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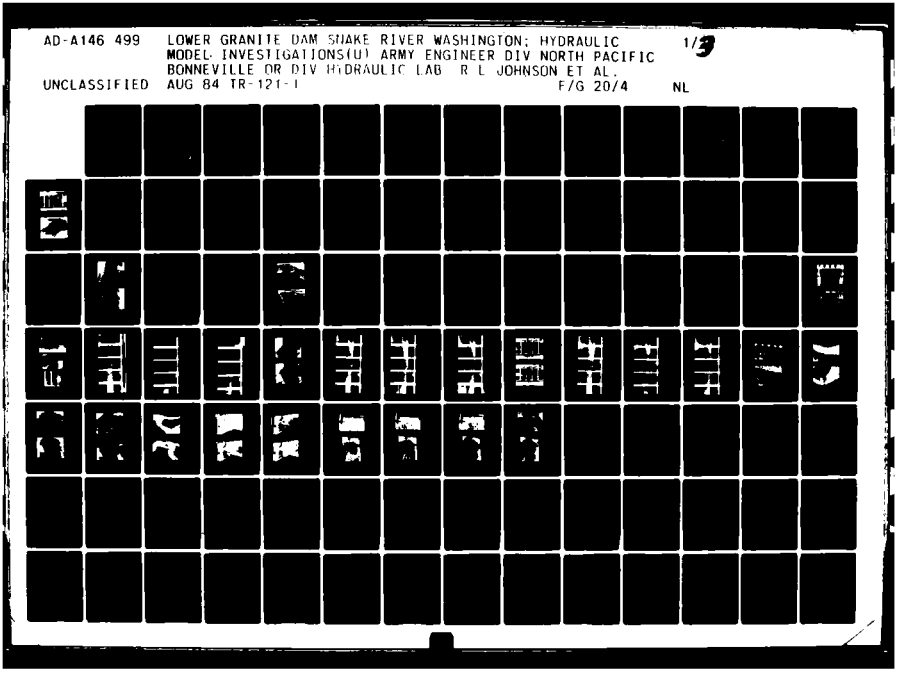

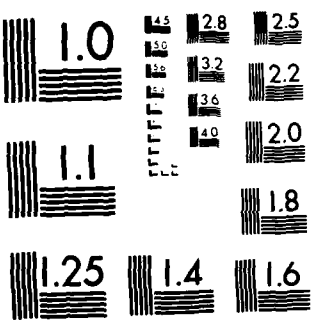

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TECHNICAL REPORT NO. 121-1

HYDRAULIC MODEL
INVESTIGATION

Lower Granite Dam
Snake River, Washington

AD-A146 499

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Flow conditions during construction and performance of the final-design structures of Lower Granite Dam were studied in a 1:100-scale comprehensive hydraulic model and in a 1:42.47-scale sectional model of the spillway. Principal features of the project included an eight-bay, tainter-gate controlled spillway, a six-unit powerhouse, a navigation lock with a maximum single lift of 105 feet, a fish collection system including a 20-foot-wide fishladder with a floor slope of 1V on 10H, and appurtenant non-overflow (continued)		

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sections. The purpose of the model study was to check the adequacy of the original design for the project and to develop revisions, if required, to benefit fish passage, energy dissipation, and power generation. Selected discharges tested included 200,000 cfs (5-year frequency and the upper limit for fish movement), 420,000 cfs (the regulated standard project flood), and 850,000 cfs (spillway design flow). Revisions to the first-step diversion and first-step cofferdam provided satisfactory fish passage conditions and a safe design for protecting the work area for flows up to 300,000 cfs. Development of deflectors on the face of the spillway necessitated several revisions to facilitate fish migration. The high velocities along the surface downstream from the deflectors produced unsatisfactory fish attraction conditions at the north fishway entrance in spite of revisions developed earlier. Use of rock groins downstream from the north fishway entrance, an extended training wall, and a non-uniform method of spillway operation made fish attraction satisfactory with flows up to 225,000 cfs. River transportation would encounter velocities up to 11 fps at a riverflow of 200,000 cfs, but velocities were 7 fps or less with flows up to 150,000 cfs.

PREFACE

Comprehensive and sectional spillway hydraulic model studies of Lower Granite Lock and Dam were authorized by the Office of Chief of Engineers on 1 October 1963 and 16 September 1965, respectively, at the request of the U.S. Army Engineer District, Walla Walla (NPW). Powerhouse skeleton unit model tests were authorized by North Pacific Division (NPD) letter dated 19 August 1970 and are reported in Appendix A to this report. The studies were conducted at the NPD Hydraulic Laboratory during the period June 1964 to January 1974.

The model studies were supervised by Messrs. H. P. Theus and P. M. Smith, Directors of the Laboratory, and A. J. Chanda and R. L. Johnson, Chiefs of the Hydraulics Branch. Engineers actively concerned with the studies were Messrs. P. M. Smith, R. L. Johnson, B. B. Bradfield, T. D. Edmister, and A. G. Nissila. They were assisted by engineering technicians F. S. Bahler, G. D. Bocksler, and D.E. Fox. This report was prepared by Messrs. R. L. Johnson, L. Z. Perkins, and M. M. Kubo.

During the course of the investigations, Mr. H. A. Smith of NPD and Messrs. G. C. Richardson and A. L. McCormmach of NPW made frequent trips to the Laboratory to observe flow conditions in the models, to discuss test results, and to correlate these results with design work that was in progress. Model demonstrations and conferences were held to obtain the advice and concurrence of navigation and fisheries interests concerning plans for navigation and fish passage at the project.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles	1.6093	kilometres
feet per second	0.3048	metres per second
cubic feet per second	0.0283	cubic metres per second
pounds (mass)	0.4536	kilograms
kilowatts	60,000	joules per second

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LOWER GRANITE DAM
SNAKE RIVER, WASHINGTON
Hydraulic Model Investigations

PART I: INTRODUCTION

The Prototype

1. Lower Granite Dam is located on the Snake River 37.2 miles upstream from Little Goose Dam and 107.5 miles upstream from the confluence of the Snake and Columbia Rivers.* Figure 1 is a vicinity map of the area. The project is the fourth multiple-purpose dam that has been constructed by the U.S. Army Corps of Engineers on the lower Snake River for electrical power, navigation, and other uses. Project layout is shown on plate 1. Principal project features include the following: an eight-bay tainter-gate-controlled spillway (crest elevation 681)**, a six-unit powerhouse having an overload capacity of 931,500 kilowatts, an 86-foot-wide by 675-foot-long navigation lock providing a maximum single lift of 105 feet, a 20-foot-wide fish ladder having a 1 vertical (V) on 10 horizontal (H) floor slope, and an adult fish collection system incorporated into the downstream portions of the spillway and powerhouse structures.

2. Recorded natural flows at the site have varied from 500 cfs (due to ice effect in January 1937) to 409,000 cfs in June 1894. The standard project flood is 420,000 cfs, and the project design discharge is 850,000 cfs which is also the probable maximum flood as regulated by upstream storage. The reservoir behind the dam will

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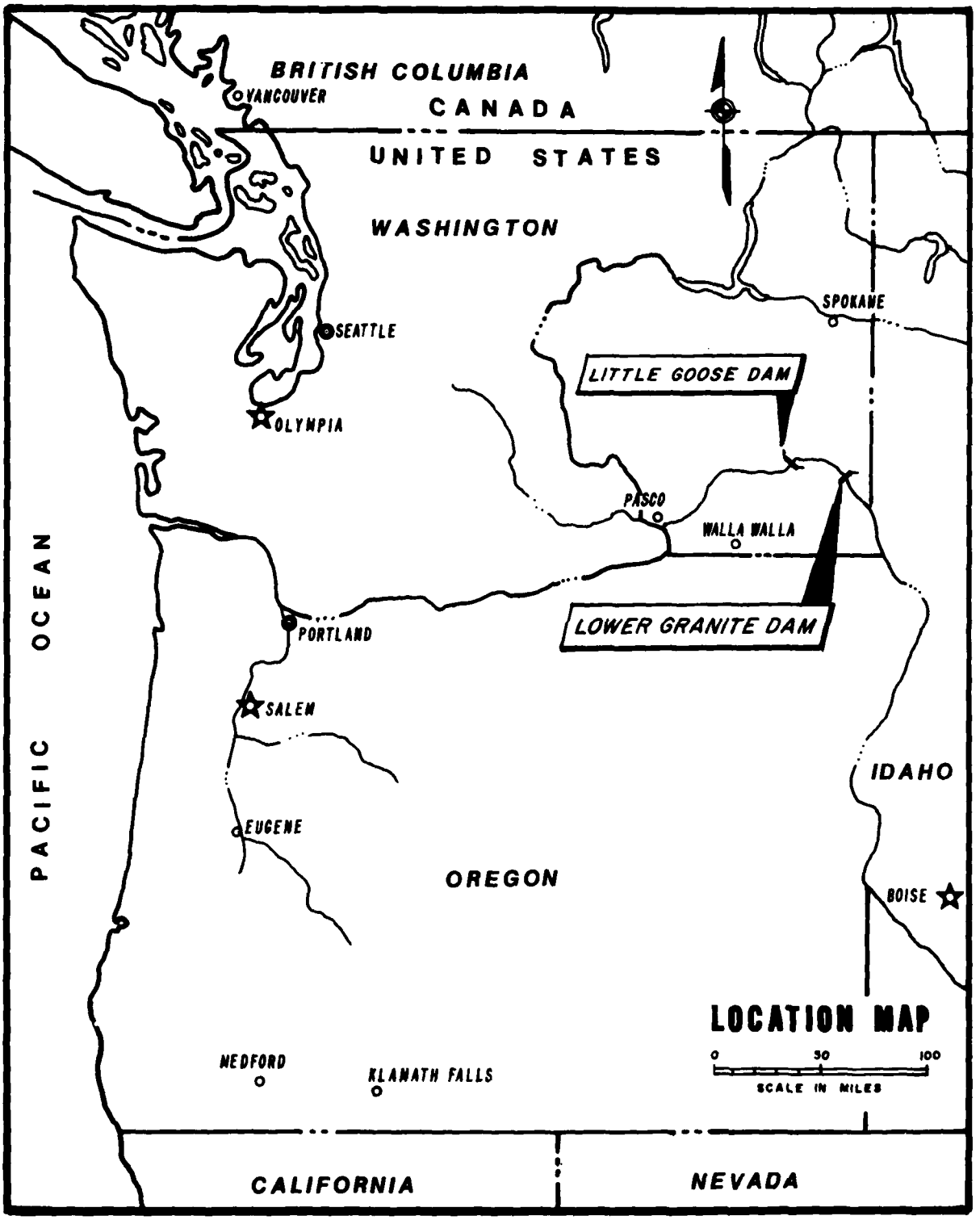
* A table of factors for converting U.S. customary units of measurement to metric (SI) units is shown on page ii.

** All elevations are in feet above National Geodetic Vertical Datum.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VANCOUVER
CANADA
UNITED STATES
WASHINGTON
SPOKANE
SEATTLE
LITTLE GOOSE DAM
OLYMPIA
PASCO
WALLA WALLA
LOWER GRANITE DAM
PACIFIC OCEAN
PORTLAND
SALEM
IDAHO
EUGENE
OREGON
BOISE
LOCATION MAP
0 50 100
SCALE IN MILES
MEDFORD
KLAMATH FALLS
CALIFORNIA
NEVADA

Figure 1

normally vary from pool elevation 738 to 733 for power pondage operation; however, adopted methods of pool regulation (except for power generation) are unique to this project. As riverflows increase, the maximum operating pool must be reduced at Lower Granite Dam to maintain a maximum elevation of 738 at the mouth of the Clearwater River near Lewiston, Idaho. For riverflows greater than 430,000 cfs, the minimum pool elevation will coincide with the free-flow rating curve for the spillway if all the riverflow is passed through the spillway (plate 2).

3. The spillway weir is an ogee-type, concrete-gravity structure (plate 3). The weir profile corresponds to the Corps of Engineers high-overflow spillway shape with a design head equal to 0.75 of the total maximum head on the crest. The 50-foot-wide, 60-foot-radius, and 60.15-foot-high crest gates are supported by the abutments and 14-foot-thick piers with elliptical noses that extend 9.25 feet upstream from the weir and 22.50 feet upstream from the crest axis.

4. Computations indicate that the spillway design discharge of 850,000 cfs could be passed through eight 50-foot-wide bays at a total head of 65.5 feet (pool elevation 746.5). A head of 48.0 feet was used to determine the spillway profile. A slope of 1V on 1H downstream from the crest curve is connected to the horizontal stilling basin by a 50-foot-radius curve. A horizontal deflector at elevation 630.0 was added during the model studies. The hydraulic-jump type stilling basin consists of a 188-foot-long apron at elevation 580.0. In this report, basin length is measured from the PI of the spillway bucket curve to the toe of the 45-degree, 13-foot-high end sill. The original plan included a runout slope of 1V on 4H from the top of end sill to the downstream topography.

The Models

Purpose

5. Although the design of hydraulic structures for Lower Granite Dam was based on experience and sound design practice, data from hydraulic model studies were required in the interests of safety, economy, and effective fish passage. The problems to be solved were so diverse that five models were used to check the adequacy of various elements and to develop revisions, if necessary. This report presents salient results of tests that were made in the spillway, comprehensive and skeleton unit (Appendix A) models. The navigation lock and fish ladder model reports were previously published.

Description

6. A three-bay section of the eight-bay spillway, upstream approach, and exit channel were reproduced in a 1:42.47-scale model (figure 2 and photograph 1). The floor of the flume upstream from the spillway was at elevation 600 (assumed average elevation of excavation) for approximately 50 feet upstream from the face of the dam and then sloped 1V on 2H to elevation 630. Downstream from the stilling basin two geometries were tested--(1) the contract condition in which the exit channel sloped 1V on 4H from the top of the end sill to elevation 610 and (2) an alternate condition in which the exit channel remained at the same elevation as the stilling basin to simulate the maximum depth of erosion assumed to occur downstream from the basin. The model floor extended approximately 1,200 feet upstream and 1,060 feet downstream from the structures.

7. The river bed and pertinent overbank areas for about 1.3 miles upstream and 1.8 miles downstream from the project axis were molded in concrete in the 1:100-scale comprehensive model

Figure 2. Side view of 1:42.47-scale spillway model.

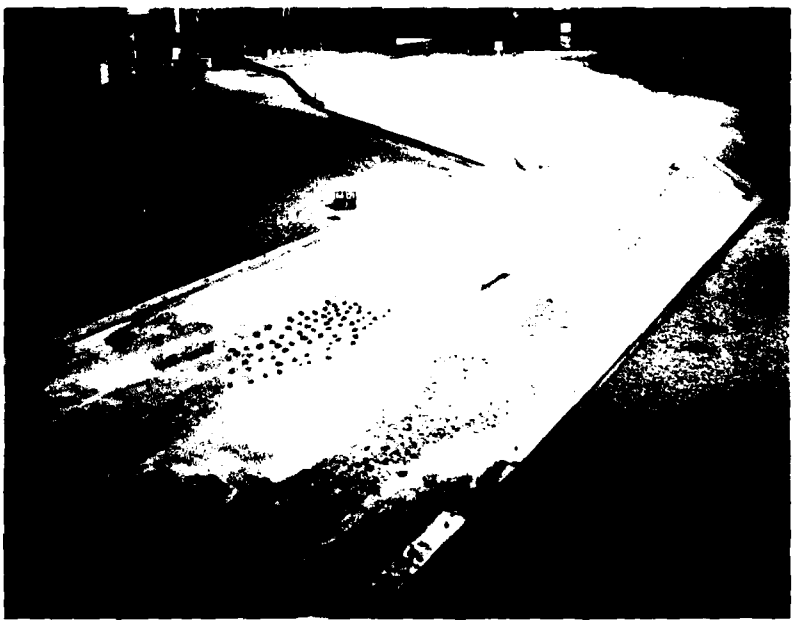

Figure 3. General view, looking upstream, of 1:100-scale comprehensive model after verification.

(figure 3 and plate 4). Sufficient overbank was included to allow reproduction of the project design discharge upstream and downstream from the dam (pool elevation 746.5 and tailwater elevation 661.2, respectively; plate 2).

8. Standard laboratory instruments and procedures were used to measure discharges, water surface elevations, current directions, velocities, and pressures (in spillway model only). Still and timed-exposure photographs were taken to supplement the test data.

Scale Relations

9. The models were geometrically similar to the prototype and were operated in accordance with Froude's law. Model-to-prototype scale relationships were as follows:

Dimension	Spillway Model	Comprehensive Model
Length	1:42.47	1:100
Area	1:1,804	1:10,000
Velocity	1:6.517	1:10
Time	1:6.517	1:10
Discharge	1:11,754	1:100,000
Roughness	1:1.868	1:2.154

PART II: TESTS IN SPILLWAY MODEL

Crest and Piers

Discharge Ratings

10. The spillway crest and piers that are shown in photograph 1 and on plate 3 were not changed during the study. Flow conditions with free flow through the bays are shown in photograph 2. A free-flow crest rating and contraction coefficients for the piers were not determined because the spillway ogee and piers were nearly identical to those previously model tested for Little Goose Dam.* Discharge and coefficient curves for free flow are shown on plate 5. The discharge and coefficient curves for free flow are shown on plate 5. The discharge coefficients were computed from the equation $C_p = Q/L'H_e^{3/2}$ in which,

C_p = discharge coefficient for crest with piers
Q = discharge in cfs
L' = net length of crest in feet
H_e = total head on crest in feet $(h+v^2/2g)$

Discharge coefficients varied from 2.95 at approximately 6 feet of head on the crest (discharge 40 cfs per foot of crest) to 4.05 at a head of 64.9 feet (discharge 2,180 cfs per foot of crest; spillway discharge 850,000 cfs). For a total head of 57 feet (normal maximum

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* R.L. Johnson and L.Z. Perkins, "Spillway for Little Goose Dam, Snake River, Washington; Hydraulic Model Investigation," Technical Report No. 114-1, April 1975, U.S. Army Engineer Division, North Pacific Division, Hydraulic Laboratory, Bonneville, Oregon.

pool elevation 738) the discharge was 678,000 cfs. Note that the prototype capacity will be slightly less since the abutment contraction effects are not included in the model data.

11. The rating curves for gate-controlled flows (plate 6) are based on nominal gate openings* and use of all spillway bays. The lower limit of gated flow represents the discharge and total head or forebay energy gradeline elevation below which the gates could not maintain stable control in the model. The maximum opening for gated flow at pool elevation 738 was not determined. Discharge coefficients for gated, multiple-bay operation of the spillway at normal pool elevation 738 (plate 7) were computed from the equation $C_n = Q/A_n \sqrt{2gh_n}$ in which,

C_n = coefficient of discharge
Q = discharge in cfs per bay
A_n = area of nominal gate opening
g = acceleration of gravity
h_n = *effective head* (vertical distance from midpoint of nominal gate opening to energy gradeline)

Pressures

12. Except for slightly different stoplog slots, the Lower Granite and Little Goose spillway crests and piers are identical. Since pressures with free flow in the Little Goose spillway model were acceptable, free-flow pressure tests were not repeated in the Lower Granite model. Pressure measurements for gated flow were required because of the 1.5-foot increase in gate trunnion elevation and accompanying change in gate seal location with respect to the crest. Pressures at the piezometers shown on plate 8 are summarized

* In this study, nominal gate opening is the vertical distance between the gate lip and the seal elevation on the spillway.

at the piezometers shown on plate 8 are summarized in table A. The minimum pressure (-5.9 feet of water) occurred at piezometer C-9 on the spillway surface 10 feet downstream from the gate seal when the gates were opened 15 feet.

Stilling Basin

13. The stilling basin (plate 3) was designed to provide optimum energy dissipation for the regulated standard project flood of 420,000 cfs and adequate dissipation to ensure safety of the project during the spillway design flow of 850,000 cfs. Performance of the stilling basin was evaluated with the tailrace excavated to elevation 610 and also with the estimated maximum probable erosion assumed to occur. For the latter condition, the spillway model reproduced an 85-foot-long berm at elevation 593 (top of end sill) followed by an 850-foot-long slope to elevation 611. Tailwater curves established for the two channel elevations at gage T-1 in the general model (plate 9) were used to control tailwater elevations 1,000 feet downstream from the crest axis in the spillway model.

14. Tests in the spillway model indicated that insufficient tailwater depth was available to maintain a satisfactory hydraulic jump (with toe at the PT of spillway bucket) during the 850,000-cfs discharge (plate 9). However, other studies have shown that stilling basin capacities indicated by sectional models may be lower than capacities of the same basin in general models having wide river channels and powerhouse tailraces which permit flow expansion and return flow to the basin. These effects were investigated in the general model by isolating segments of the stilling basin with walls that blocked flow expansion and return flow. Good agreement existed between basin capacity curves that were obtained with three bays isolated in the comprehensive model and basin capacity curves in the three-bay spillway model. With eight bays isolated in the

general model, the minimim tailwater required to maintain a good hydraulic jump in the stilling basin was 17 feet higher for a discharge of 850,000 cfs than it was without the walls. Since normal tailwater depths in the general model were more than adequate, the original stilling basin was considered satisfactory.

Flow Deflectors

15. In 1971 and 1972, extensive efforts were directed toward reducing the levels of nitrogen supersaturation that occur when aerated flow plunges into a stilling basin. There is no evidence that flow through the turbine/generator units increased the dissolved gas levels in the river. Laboratory and field tests have shown that survival of adult and juvenile salmon and steelhead trout in the Columbia and Snake Rivers was being jeopardized by a gas-bubble disease produced by high levels of dissolved gases in the river. Deflectors placed near the base of a spillway (photograph 6) were the most promising short-term means of reducing gas supersaturation by directing spilled flow horizontally into the stilling basin. Horizontal deflection of the water could minimize deep plunging flow--the primary source of supersaturation with air (chiefly nitrogen). Principal emphasis was placed on developing deflectors that would be most effective for Snake River flows with approximate flood frequencies of 2, 5, and 10 years (171,000, 212,000, and 252,000 cfs, respectively).

16. Photographs 3 through 5 show the original flow conditions in the spillway model for discharges of 5,210, 10,150, and 15,100 cfs per bay. With six powerhouse units operating, these flows represented Snake River discharges of 171,000 through 252,000 cfs. For all discharges, flow plunged to the stilling basin floor and entrained air was dispersed throughout the basin when the model was

operated without deflectors. Zones of aeration and directions of flow in and immediately downstream from the basin are shown on plate 10.

Effect of Deflectors

17. Three lengths of deflectors at several elevations (plate 11) were tested. The 15-foot deflector at elevation 634 and the 12.5-foot deflector at elevation 630 are shown in photograph 6. The length of the deflector is defined as the length of the horizontal projection from the downstream end of the deflector to the original crest profile. Two variations of the lip--one with the lip sloped upward 10 degrees and one with a downward slope of 5 degrees--were less satisfactory than a horizontal 12.5-foot deflector at elevation 630. Flow conditions with this design are shown in photographs 7 through 9 and on plates 12 and 13. A distinct advantage of the shorter deflector was the greater range of discharges in which stable flow existed in the stilling basin. Unstable flow, with the nappe oscillating between skimming and plunging flow, existed with spillway discharges of 23,000 through 36,000 cfs per bay. Flow conditions existing in the stilling basin with the standard project flood (420,000 cfs river flow and 37,170 cfs per bay) are shown in photograph 10.

Flow Deflectors and Dentates

18. Dentates on or just upstream from the deflector were installed to reduce the energy of flow into the stilling basin and thus reduce the amount of deeply entrained air. Eight arrangements of 1.8-foot-wide by 2.16-foot-high dentates were tested with the 12.5-foot deflector at elevation 630. The most satisfactory arrangement was Plan H (plate 14) which provided a stable nappe, good energy dissipation, and less air entrainment than with the deflector alone. The dentates allowed approximately 2,000 cfs more discharge per bay

to be discharged without unstable flow in the stilling basin (plate 13). Flow conditions with the Plan H dentates are shown in photographs 11 through 13 and on plate 15.

19. Pressures on the 12.5-foot deflector with Plan H dentates were measured at the locations shown on plate 14. A piezometer was placed in the upstream face of one dentate in each row to measure impact pressures (piezometers D-1, D-3, and D-5) and on the ogee in the low-pressure zone behind the dentates (piezometers D-2, D-4, and D-6). The lowest pressures were recorded at piezometer D-2 (-32 feet) with a discharge of 10,150 cfs per bay and at piezometer D-6 (-22 feet) with a discharge of 106,250 cfs per bay (table B). Average pressures at these locations were -22 and -18 feet of water. In models that are subjected to atmospheric pressure, water manometer pressures lower than -10 feet indicate that cavitation is likely to occur in the prototype. The greatest pressure differential on a dentate was 112 feet of water at a discharge of 10,150 cfs per bay (maximum difference measured between piezometers D-1 and D-2).

Prototype Tests

20. A 12.5-foot deflector with 10-degree curved lip and the Plan H dentates were installed for tests in bay 2 of the Lower Monumental Dam spillway. Since the configuration of Lower Monumental spillway is nearly identical to those of Lower Granite and Little Goose, the prototype test results were considered to be applicable to all three projects. The levels of dissolved nitrogen (N_2) on 3 April and 12 April 1972 were 103.1 to 108.4 percent in the forebay, 106.1 to 114.7 percent in flow just downstream from bay 2, and 121.0 to 129.9 percent downstream from bay 3 with comparable flows. When the spillway was inspected in August 1972, one dentate in the middle row and all but the two outside dentates in the bottom row were missing. Damage to the concrete downstream from the top row of dentates due to cavitation was severe (photograph 14).

21. The concrete was repaired, one dentate in the middle row was replaced in bay 2, and a 12.5-foot horizontal deflector was installed in bay 4 during the fall and winter of 1972-1973. Measurements in 1973 indicated that nitrogen level in flow through bays 2 and 4 was much lower than in bays without deflectors. There was no significant difference between bays 2 and 4. Because of the severe and intolerable cavitation damage to the spillway concrete plus the lack of demonstrated effectiveness of the dentates, they were deleted from consideration at Lower Granite spillway and removed from the prototype spillway at Lower Monumental Dam.

Part III: TESTS IN COMPREHENSIVE MODEL

Verification

22. Details of the 1:100-scale comprehensive model are described in paragraph 7 and shown on plate 4. During the process of verification, roughness in the form of stippled concrete, small gravel, and crushed rock (figure 3) was adjusted until agreement between model and prototype flow patterns and water surface elevations was satisfactory. Prototype flow measurements for six Snake River discharges and water surface elevations at several locations between 20,300 and 255,000 cfs were used to adjust model roughness. The tailwater was controlled according to the curves shown on plate 2. After verification, model water surface elevations were within 0.4 foot of prototype elevations for riverflows less than 192,000 cfs and 0.6 foot for the 255,000-cfs discharge.

First-Step Diversion

Description

23. One cofferdam, consisting of 32 steel cells and flanking rockfill embankments extending to high ground on the left (south) bank, enclosed all principal concrete structures and 426 feet of the downstream lock guard wall (plate 20). The cofferdam elevations were selected to provide protection for a riverflow of 300,000 cfs with the Little Goose pool at elevation 638. However, both the natural tailwater and the tailwater controlled by Little Goose Dam had to be considered since the Little Goose pool was scheduled to be raised during the construction of Lower Granite. The river was to be diverted through an excavated channel on the north side of the cofferdam while construction was completed within the cofferdam.

The diversion channel was to occupy all of the available area between the river leg of the cofferdam and a temporary shoofly for the Camas Prairie Railroad on the north bank. The diversion channel shown on plate 16 was about 600 feet wide and was to be excavated to elevation 605 opposite the cofferdam. The excavation extended to the thalweg of the existing river channel (elevations 615 upstream and 610 downstream).

24. Initial construction of the cofferdam and excavation of the diversion channel were to be accomplished inside a 6,880-foot-long dike with top at elevation 645 (plates 16 and 17). This so-called "contractor's dike" was designed to protect the working area against a maximum river discharge of 250,000 cfs. Final closure of the dike would be made in one winter season after all major runs of adult fish had passed upstream. Since no hydraulic problems were expected, model tests of the closure were not required.

Plan A "Contractor's Dike" (Original Design)

25. Tests of the Plan A "contractor's dike" indicated that velocities of 11 and 14 fps would exist at a bend in the dike opposite gage 7 during river discharges of 100,000 and 200,000 cfs, respectively (plates 16 and 17). Natural tailwater elevations were used during the tests of the "contractor's dike." For design, it was assumed that velocities of 9 fps or greater for a distance of more than 60 feet would stop the upstream passage of fish. Heavy riprap would be needed to protect the dike in areas subjected to velocities of 14 fps or greater. The model showed that rock groins along the right bank of the dike would reduce velocities enough to allow fish to pass upstream.

Plan C "Contractor's Dike" (Recommended Design)

26. A shorter and less costly dike was recommended. Tests of this plan also indicated that groins were required to reduce velocities of 14 fps or greater which existed along the face of the dike during river discharges of 100,000 and 200,000 cfs. Surface flow patterns with the 100,000-cfs flow are shown in photograph 15. With three groins, maximum velocities along the dike were 8 fps (downstream portion) and 10 fps (upstream fill) during the 200,000 cfs flow (plates 18 and 19). A maximum velocity of 12 fps existed across the noses of the groins with the 200,000-cfs flow but was considered acceptable because it occurred for a very short distance. Fish migrating upstream would encounter velocities of 9 fps or greater in the center portion of the channel and would have to seek lower velocities along the shores. The upstream portion of Log Cabin Island was overtopped by a river discharge of 200,000 cfs. A short fill constructed to elevation 645 at the center of the island was overtopped at 225,000 cfs; the upstream fill, also with top at elevation 645, was overtopped at 250,000 cfs.

First-Step Cofferdam

Plan A (Original Design)

27. Initial studies of the Plan A first-step cofferdam (photograph 16) were made with both natural tailwater elevations and tailwater elevations controlled by Little Goose Dam and did not consider the right bank disposal fill (Waste Area No. 3 on plate 16) to be in place. For natural tailwater with a discharge of 200,000 cfs, maximum velocities of 11 to 14 fps existed within 50 feet of the right bank (plate 20). Since velocities 5 feet above the bottom averaged

11 to 12 fps and reached a maximum of 14 fps, erodible material would be scoured from the channel until a stable condition of increased depth and decreased velocities was reached.

28. Water surface elevations along the cofferdam are listed in table C. With natural tailwater, the elevation 650 upstream leg and the elevation 645 cells were overtopped by river discharges of 400,000 and 480,000 cfs, respectively. With the Little Goose pool at elevation 638, the upstream leg and the cells were overtopped at 345,000 cfs. With natural tailwater, the earthfill to the south bank could be closed at differential heads (difference between gages 7 and 11) of 5.0 feet at 20,000 cfs, 3.3 feet at 100,000 cfs, and 6.4 feet at 300,000 cfs.

Development of Final Design

29. The Plan A right bank disposal fill confined flow to the area south of gage 6-A and increased velocities in the diversion channel. Surges up to 4.2 feet resulted from pulsating flow around cell 32 during the 200,000-cfs discharge. The channel entrance was revised and a finger dike was added to protect the left bank and cell 32 from high-velocity flow (Plan C approach). Three rock groins along the right bank were positioned by experimentation in the model (Plan K groins). Details of the final design are shown in photograph 17 and on plate 21.

Plan A Cofferdam, Plan C Approach, and Plan K Groins (Final Design)

30. The final-design first-step cofferdam and diversion channel were tested with natural tailwater for discharges of 25,000 through 480,000 cfs and with Little Goose pool elevation 638 and discharges between 50,000 and 355,000 cfs. Water surface elevations at river

gages and near the cofferdam are shown in table D. The higher cofferdam tailwater produced with the Little Goose pool at elevation 638 was pertinent only to establish the overtopping flows for the cofferdam. With natural tailwater, overtopping of the upstream leg of the earthfill occurred upstream from the spur dike at a riverflow of 400,000 cfs. Cells 8 through 10 and the earthfill downstream from the spur dike were overtopped at 480,000 cfs. The head on the diversion channel (gages 6 through 16) varied from 7.0 feet at 25,000 cfs to 12.5 feet at 480,000 cfs. The head on the cofferdam (gages 7 through 11) decreased from 5.1 feet at 25,000 cfs to 3.9 feet at 100,000 cfs and then increased to 8.7 feet at 400,000 cfs.

31. Flow conditions and velocities for river discharges of 50,000 to 300,000 cfs with natural tailwater are shown on plates 21 through 24. Flow conditions for fish passage and bank protection were satisfactory for river discharges of 50,000 and 100,000 cfs. Velocities along the right side of the diversion channel did not exceed either 5 fps on the bank or 9 fps above the toe of the bank and across the nose of a groin. Flow patterns with a discharge of 200,000 cfs are shown in photograph 18 and on plate 23. At 300,000 cfs, velocities were 10 fps along the bank, 17 fps above the toe, 16 fps across the nose of a groin, and 21 fps in midchannel (plate 24). The spur dike was above water and had no affect during discharges less than 200,000 cfs. At 300,000 cfs, the dike diverted flow away from the upstream fill and reduced surges at cell 32 to an occasional disturbance 1 or 2 feet high (surges were 4.2 feet high with the original design). Flow patterns and drops in head at the temporary fishway between cells 31 and 32 were considered satisfactory.

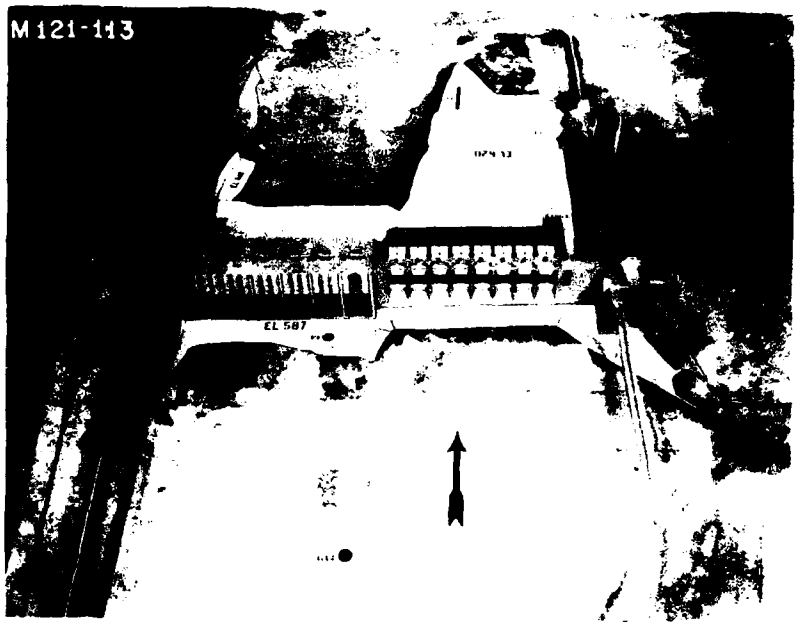
Plan A (Original Design) Structures and Tailrace

Description

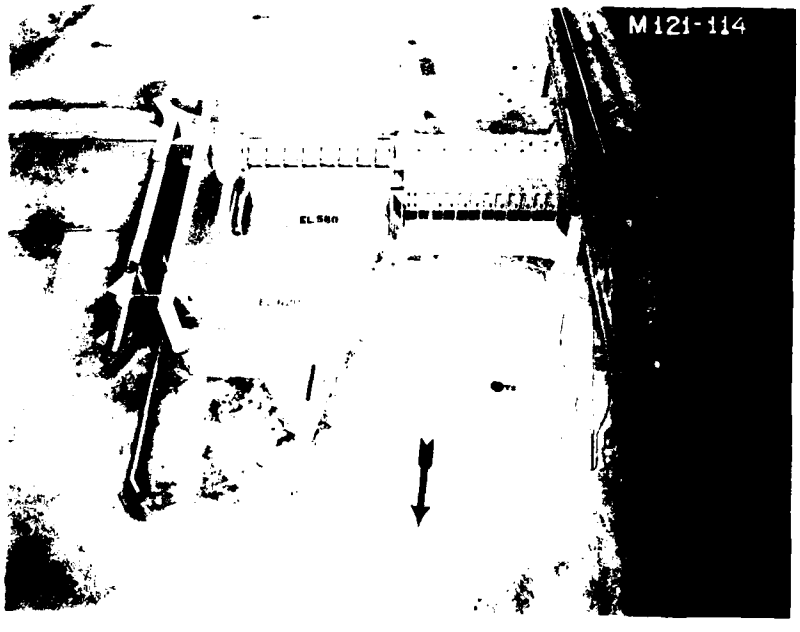
32. The original structures and tailrace plan are shown in figure 4 and on plate 25. Due to the excavated diversion channel, the navigation lock and spillway were located at approximately midstream. The navigation lock is adjacent to the shore at other projects on the Columbia and Snake Rivers. To eliminate 90-degree bends in the emptying culverts, the navigation lock was originally designed with two outlets that were directed downstream at an angle of 45 degrees from the structure. The downstream leg of the first-step cofferdam and the spillway tailrace inside the cofferdam were to be excavated to elevation 620. The downstream end of Log Cabin Island outside of the first-step cofferdam was not to be removed.

Test Results

33. Tests in the model indicated that revision of the initial structures and excavation was required. With three powerhouse units in operation, maximum velocities over the unexcavated portion of Log Cabin Island ranged from 12 fps during a river discharge of 150,000 cfs to 25 fps at 340,000 cfs (plate 26). High velocities along the navigation lock guide wall and at the downstream end of the wall would delay or block fish migrating upstream along the right bank. Outflow from the right outlet of the navigation lock would attract fish into a large slack water area from which there is no facility for fish passage. Water surface elevations over the navigation lock outlets were influenced by spillway discharges and differed from 1.1 feet at a riverflow of 150,000 cfs to 3.4 feet at 340,000 cfs.



Upstream view



Downstream view

Figure 4. Plan A structures, stilling basin, and tailrace.

34. A 1.0-foot drop in water surface elevations from the south to north fishway entrances was desired for efficient operation of the fish collection and transportation system. A single fish ladder and auxiliary attraction-water supply system are provided on the south shore for all adult fish that enter the system at either the powerhouse at the south shore or the north side of the spillway. Those fish that pass into the entrances at the north side of the spillway will traverse the width of the spillway structure in a tunnel. This channel joins the powerhouse collection channel at the north or spillway side of the powerhouse; thus, it was desirable to attain a lower water surface elevation at the north side of the spillway to insure adequate attraction and transportation flow for adult-fish passage. In this case, "adverse" indicates a higher tailwater water surface at the north entrance than at the south shore. Existing conditions produced an "adverse" head of -0.6 foot at 150,000 cfs, -0.3 foot at 225,000 cfs (the design maximum discharge for good attraction at fishway entrances), and a positive head of 0.6 foot at 340,000 cfs.

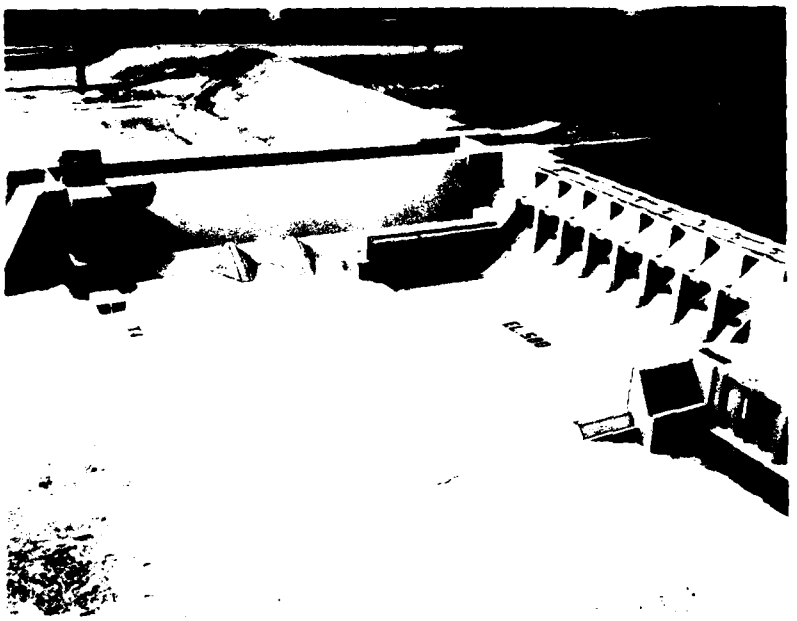
Development of Final Design

35. Tests of alternative stilling basin and tailrace plans led to the conclusion that the original basin would be adequate and that high velocities downstream from the spillway would erode the riverbed approximately to the contours shown on plate 27. The navigation lock-emptying system was revised so that both outlets were on the river side of the lock to eliminate a possible fish trap between the navigation lock and the left bank. Limits for disposal area were determined and fishway entrances were revised. The south fishway entrance, originally between the upwelling from the powerhouse outflow and the face of the powerhouse, was revised to include a second entrance downstream from the upwelling for easier access by migrating fish.

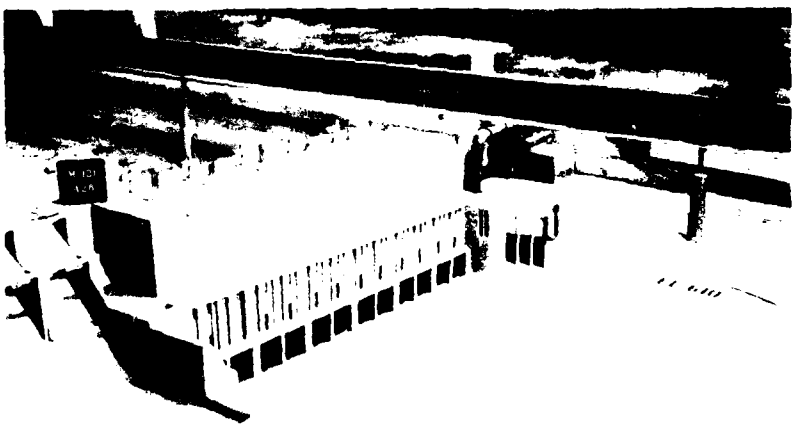
36. Before the decision was made to place a 12.5-foot deflector at elevation 630 in all spillway bays, model tests had been completed and the overall plan was considered to be acceptable. High surface velocities off the deflector caused undesirable conditions at the north fishway entrance. A strong eddy (upstream velocities of 9 to 15 fps) existed along the lock wall during river discharges of 200,000 and 225,000 cfs, respectively. The most effective revisions at the north fishway entrance included two rock groins along the navigation lock wall and a stepped extension of the north training wall. Flow conditions with these revisions were acceptable, but "adverse" heads up to -0.4 foot still existed between the north and south fishway entrances. Reducing the spill in bays 7 and 8 reduced velocities across the noses of the rock groins and improved heads for fishway operation.

Final Design

37. Details of the final structures and excavation plan are shown in figure 5 and on plate 27. Flow conditions for selected discharges and methods of project operation are shown in photographs 19 through 24 and on plates 28 through 42. Water surface elevations are summarized in table E. With the spillway closed and powerhouse units 1 through 3 operating during river discharges of 25,000 and 50,000 cfs, a large slow eddy occurred in the stilling basin (plates 28 and 29). Outflows of 500 cfs each from the north and unit 6 fishway entrances appeared adequate to attract fish from the eddy. A large eddy that extended far downstream formed in front of the powerhouse when less than three units were operated. If possible, unit 1 should be operated to maintain downstream flow along the left bank during fish migrations.



Spillway, navigation lock, lock outlet, and groins



Powerhouse and adjacent pump intakes and fishway entrances

Figure 5. Final design structures.

38. Conditions for fish passage were acceptable when six powerhouse units were operated with a river discharge of 200,000 cfs (plates 38 and 39). Small eddies existed near the groins on the right bank, and some upstream flow occurred across the noses of the groins; however, the quantity and direction of attraction flow from the north fishway entrance were satisfactory. With three powerhouse units, increased flow over the spillway required that two gates at each end of the spillway be adjusted to provide good flow conditions at the adjacent fishway entrances. Gate openings for actual operating conditions will be determined in the prototype. Velocities during river discharges greater than 200,000 cfs were considered high enough to block fish at the navigation lock outlet, along the lock wall, and at the end of the north training wall. The flow deflectors produced stable skimming flow in the stilling basin for spillway discharges to 250,000 cfs. Unstable, partly plunging flow gradually changed to full plunging flow as discharge increased from 250,000 to 420,000 cfs.

39. Velocities in the downstream approach to the lock did not exceed 7 fps for river discharges to and including 150,000 cfs (plates 28, 29, and 31 through 34). River traffic will encounter velocities of 11 fps at 200,000 cfs and 15 fps at 420,000 cfs (plates 36 and 40). At 850,000 cfs maximum velocities were 32 fps in midstream, 22 fps at the lock outlet, and 15 fps at the downstream end of the lock guidewall. Waves 16 to 20 feet high were measured at the rock groins near the north fishway entrance.

IV: SUMMARY

40. A 1:100-scale comprehensive model and a 1:42.47-scale sectional spillway model were used to verify the final design of the Lower Granite Dam project.

41. Modifications to the diversion facilities were developed in the comprehensive model to provide more-acceptable fish passage conditions during construction activities. The modifications included a finger dike extending from the left bank of the cofferdam to protect a temporary fish ladder located at cell 32 of the cofferdam and rock groins along the banks of the diversion structures to reduce velocities sufficiently to allow upstream fish passage.

42. The model revealed that both outlets of the navigation lock-emptying system were required to exit from the river side of the lock to prevent potential for fish entrapment on the shoreside of the lock.

43. A 12.5-foot horizontal deflector on the face of the spillway at elevation 630 was developed in the sectional model to reduce the potential for nitrogen supersaturation during spillway usage. A revised, stepped extension of the stilling basin's north training wall and two rock groins along the navigation backwall were required to minimize undesirable flow conditions at the north fishway entrance resulting from high surface velocities off the spillway deflector.

44. The model revealed that the south fishway entrance was located in an area subjected to upwelling from powerhouse operation. A second fishway entrance was incorporated downstream from the upwelling area to provide easier access for migrating fish.

TABLE A

PRESSURES ON CREST AND PIERS

Gated Flow: Pool Elev 738.0

Piezometer			Nominal Gate Opening in Feet								
			3	5	7	10	15	20	25	30	35
No.	Station	Elev	Head on Piezometer in Feet of Water								
C-7	10+10.0	679.7	8.3	7.7	8.2	8.6	8.8	9.0	8.7	8.6	8.8
C-8	10+15.0	678.2	-1.3	-2.7	-2.5	-1.5	-0.2	1.1	2.2	3.1	3.5
C-9	10+20.0	676.3	-1.0	-2.8	-3.4	-4.1	-3.9	-3.4	-2.1	-1.2	-0.4
C-10	10+30.0	670.9	-0.1	-1.0	-1.6	-2.4	-3.5	-4.1	-3.7	-3.2	-2.4
C-11	10+40.0	663.9	-0.4	-1.3	-2.0	-2.9	-4.0	-4.6	-4.6	-4.5	-4.0
C-12	10+53.1	652.1	0.6	-0.1	-0.3	0.7	0.4	0.9	1.7	2.0	2.9
C-20	9+95.2	680.5	55.9	54.6	52.1	48.5	42.4	37.1	30.9	25.1	19.3
C-21	9+98.4	680.9	55.1	53.2	50.0	45.7	38.5	32.2	27.6	22.6	17.1
P-8	9+95.2	681.5	54.7	52.7	49.3	44.5	34.0	25.0	16.5	11.0	7.9
P-10	9+98.4	681.9	54.1	51.8	48.2	43.6	35.3	29.4	23.3	18.6	12.1
P-12	10+05.0	681.6	48.1	39.5	33.9	28.7	24.0	21.2	19.1	17.5	15.2
P-14	10+10.0	680.7	6.3	8.7	9.7	10.3	10.6	10.6	10.9	10.9	10.3
P-16	10+15.0	679.2	0.4	-1.0	-0.5	0.7	2.0	3.3	4.7	5.8	6.4
P-18	10+20.0	677.3	0.1	-1.3	-2.1	-2.3	-1.8	-0.8	-0.1	2.3	3.5

NOTES: 1. Spillway details are shown on plate 2.

2. Piezometer locations are shown on plate 8.

TABLE B

PRESSURES ON SPILLWAY OGEE, DEFLECTOR, AND DENTATES

Piezometer			River Flow 171,000 CFS, Spwy 5,210 CFS Per Bay, Tailwater Elev 641.0			River Flow 212,000 CFS, Spwy 10,100 CFS Per Bay, Tailwater Elev 642.2			River Flow 252,000 CFS, Spwy 15,100 CFS Per Bay, Tailwater Elev 643.2			River Flow 300,000 CFS, Spwy 21,350 CFS Per Bay, Tailwater Elev 645.1			River Flow 420,000 CFS, Spwy 37,170 CFS Per Bay, Tailwater Elev 649.4			River Flow 850,000 CFS, Spwy 106,250 CFS Per Bay, Tailwater Elev 656.5		
No.	Station	Elev	Head on Piezometer in Feet of Water																	
			Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Pressures Without Dentates																				
D-2	10+67.8	637.4	2	1	1	4	3	3	12	9	11	20	18	19	37	35	36	63	59	61
D-3	10+76.1	632.4	16	14	16	35	32	34	44	42	43	54	50	52	61	59	60	83	79	81
D-4	10+85.9	630.8	4	3	4	5	4	4	11	10	10	20	16	18	29	26	28	49	45	47
D-7	10+87.7	629.8	2	2	2	3	2	3	4	2	3	5	2	4	5	3	4	17	15	16
D-8	10+87.7	629.8	11	10	11	7	4	5	7	3	5	6	0	3	8	2	5	3	- 4	0
D-9	10+87.7	629.8	10	9	10	6	4	5	6	2	4	6	0	3	8	0	4	2	- 5	- 1
Pressures With Dentates																				
D-1	10+68.4	638.3	68	48	60	80	48	73	82	72	78	82	74	78	75	70	74	87	76	82
D-2	10+67.8	637.4	2	- 2	- 1	- 4	-32	-22	-10	-24	-17	- 6	-10	- 8	15	5	9	39	29	34
D-3	10+76.1	632.4	29	19	29	49	60	46	55	48	52	62	54	58	64	58	61	79	74	77
D-4	10+76.5	630.8	0	- 1	0	0	3	0	11	9	10	16	14	15	29	27	28	52	48	51
D-5	10+85.0	631.3	21	12	16	49	36	39	45	40	42	44	38	40	58	51	54	88	82	86
D-6	10+85.9	630.0	5	3	4	- 5	- 9	- 7	-10	-15	-12	-12	-18	-14	-12	-20	-15	-14	-22	-18
D-7	10+87.7	629.8	8	7	8	9	7	8	7	5	6	8	4	6	6	- 3	0	6	1	3
D-8	10+87.7	629.8	10	9	10	9	8	8	8	7	7	8	4	6	8	- 4	1	- 2	-11	- 7
D-9	10+87.7	629.8	9	8	9	8	6	7	7	5	6	7	3	5	9	2	0	4	0	3

NOTE: Piezometer locations and details of deflector and dentates are shown on plate 4.

TABLE B

TABLE C

TABLE C

WATER-SURFACE ELEVATIONS

[illegible] Cofferdams and Diversion Channel

Location	Natural Flow									Lift to Ocean Pool Elev 650.0						
	River Discharge in 1,000 CFS															
	50	100	200	250	300	350	400	450	500	50	100	150	200	300	340	345
	Water-Surface Elevations in Feet - MSL															
A	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	646.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
F	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	
G	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	-	
Cell																
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Gage																
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* [illegible] - N[illegible] observed

NOTES: 1. Observation locations are shown on plates 4 and 20.

2. Cofferdam and diversion channel details are shown on plate 20.

TABLE D

WATER-SURFACE ELEVATIONS

Final Design First-Step Cofferdam and Diversion Channel

Location	Natural Tailwater								Little Goose Pool Elev 638.0					
	River Discharge in 1,000 CFS													
	25	50	100	200	300	350	400	480	50	100	200	300	340	355
Cell No.	Water-Surface Elevations in Feet - MSL													
31 U/S	-	-	627.3	634.8	641.4	644.7	646.8	651.5*	638.6	639.5	642.1	645.9	647.5	648.6
D/S	-	-	626.5	632.2	636.2	637.7	639.8	642.2	638.4	638.8	640.1	642.3	643.0	643.8
10	-	-	-	-	-	639.3	641.7	645.2*	638.3	638.9	640.7	643.1	644.8	645.2*
8	-	-	-	-	-	639.2	642.0	645.2*	638.4	638.8	640.7	643.6	644.4	644.9
Groins														
Sta 82+00 U/S	-	-	627.0	632.3	636.7	643.0	645.6	650.0	638.3	638.9	641.7	645.3	646.9	647.8
D/S	-	-	626.9	631.0	634.5	637.8	639.3	642.1	638.1	638.6	640.5	643.0	644.0	644.5
62+00 U/S	-	-	626.9	633.7	639.0	641.1	643.8	647.4	638.3	638.8	641.5	644.8	646.0	646.6
D/S	-	-	626.2	631.9	635.7	637.7	639.2	642.4	638.3	638.8	640.5	643.0	643.9	644.5
54+00 U/S	-	-	626.3	634.7	640.6	638.5	640.5	643.7	638.1	638.7	640.4	643.4	644.3	644.9
D/S	-	-	625.2	632.9	635.5	635.9	637.4	639.8	638.1	638.5	639.9	642.0	642.9	643.5
Spur Dikes														
N 3500 E 9260	Dry	Dry	Dry	638.5	645.1	648.0	650.7	655.6*	638.3	639.5	643.3	648.1	650.0*	651.0*
N 3500 E 9180	Dry	Dry	Dry	Dry	641.7	644.0	646.3	651.0*	638.2	639.1	642.0	645.6	647.3	648.1
Gage No.														
4	627.5	630.6	635.0	641.8	647.5	650.0	652.5	656.7	638.6	640.4	645.0	649.7	651.6	652.4
5	626.5	629.1	632.1	638.1	644.1	649.0	651.8	656.3	638.4	639.7	643.9	649.1	651.0	651.8
6	623.0	625.9	630.2	637.6	643.9	646.8	649.8	654.1	638.3	639.5	643.0	647.5	649.3	650.1
7	622.5	625.4	630.1	638.0	644.3	647.3	650.4*	654.9*	638.4	639.6	643.3	648.0	650.0	650.7*
10	619.2	622.0	626.6	633.7	639.7	642.3	645.0	649.5	638.2	639.0	641.5	645.0	646.4	647.0
11	617.4	621.3	626.2	632.5	637.2	639.4	641.4	644.9	638.1	638.7	640.8	643.5	644.8	645.2
13	616.7	620.0	624.7	630.8	635.1	637.1	638.8	641.5	638.1	638.6	640.3	642.7	643.8	644.2
14	619.3	622.6	626.9	632.8	637.4	639.6	641.7	644.9	638.2	638.9	640.9	643.7	645.0	645.5
15	616.9	620.1	624.9	631.1	635.6	637.8	639.9	643.0	638.2	638.8	640.5	643.2	644.3	644.8
16	617.0	620.3	625.1	631.3	635.4	637.3	639.0	641.6	638.3	638.7	640.3	642.6	643.7	644.2
17-TW	616.5	619.8	624.2	630.3	634.7	636.8	638.8	641.8	638.2	638.7	640.4	642.8	643.9	644.4
18	616.8	620.0	624.8	331.0	635.4	637.9	639.9	642.4	638.2	638.7	640.4	642.9	644.0	644.6

* Overtopping adjacent to gage

\- No data observed

NOTE: Locations of observations are shown on plates 4 and 21 to 24.

TABLE D

TABLE 5

WATER-SURFACE ELEVATI

[illegible] and Ex

River Discharge in CFS	Flow Distribution in CFS										Water-
	Powerhouse		Spillway	River Gages							Spwy
	Units	Flow		18	17 (TW)	16	15	[illegible]	[illegible]	[illegible]	[illegible]
5,000	1 to 5	4,9[illegible]5	0	6[illegible].0	6[illegible].0	6[illegible].1	6[illegible].0	[illegible]	[illegible]	[illegible]	6[illegible].1
[illegible],000	1 to 5	4,9[illegible]5	0	6[illegible].[illegible]	6[illegible].0	6[illegible].1	6[illegible].0	[illegible]	[illegible]	[illegible]	6[illegible].2
50,000	1 to 5	49,9[illegible]5	0	6[illegible].	[illegible]	6[illegible].2	6[illegible].	[illegible]	[illegible]	[illegible]	[illegible]
50,000	1 to 5	49,9[illegible]5	0	6[illegible].	6[illegible].	[illegible]	6[illegible].	[illegible]	[illegible]	[illegible]	[illegible]
100,000	1 to 5	64, 00	[illegible],7[illegible]5	6[illegible].7	[illegible]	6[illegible].2	6[illegible].	[illegible]	[illegible]	[illegible]	[illegible]
100,000	1 to 6	99,[illegible]5	0	6[illegible].	[illegible]	[illegible]	[illegible]	.6	[illegible]	[illegible]	[illegible]
100,000	1 to 6	99,[illegible]5	0	6[illegible].7	[illegible]	6[illegible].	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100,000	Closed	0	100,000	6[illegible].7	6[illegible].7	[illegible]	6[illegible].	[illegible]	[illegible]	[illegible]	[illegible]
150,000	1 to 5	66,000	[illegible]5,[illegible]5	6[illegible].4	6[illegible].4	6[illegible].5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150,000	1 to 6	1[illegible],000	[illegible]7,[illegible]5	6[illegible].5	6[illegible].4	6[illegible].6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]0,000	1,5, 4	6[illegible],10[illegible]5	94,820	6[illegible].7	6[illegible].6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
160,000	1,5, 4	6[illegible],10[illegible]5	94,820[1]	6[illegible].7	6[illegible].7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
180,000	1 to 6	129,0[illegible]5	34,880	6[illegible].7	6[illegible].6	6[illegible].	6[illegible].	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]00,000	1,5, 4	6[illegible],67[illegible]5	134,050	[illegible]0.[illegible]	640.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible],00,000	1,5, 4	6[illegible],67[illegible]5	134,050[1]	[illegible]0.4	640.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]00,000	1 to 6	1[illegible]9,[illegible]5	70,000	[illegible]40.5	640.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]00,000	1 to 5	67,[illegible]50	132,035	[illegible]40.4	640.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]00,000	1 to 5	67,[illegible]50	132,035[2]	[illegible]0.4	640.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]50,000	1 to 6	1[illegible]1,400	118,525	[illegible]41.7	[illegible]41.[illegible]	[illegible]41.8	[illegible]41.[illegible]	[illegible]	[illegible]	6[illegible].	
340,000	1 to 5	69,960	270,565	[illegible]44.1	[illegible]45.[illegible]	[illegible]44.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
340,000	1 to 6	13[illegible],7[illegible]0	201,205	[illegible]44.[illegible]	[illegible]45.[illegible]	[illegible]44.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
340,000	Closed	0	340,000	[illegible]44.[illegible]	[illegible]45.[illegible]	[illegible]44.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]0,000	1 to 5	67,[illegible]90	352,035	[illegible]46.4	[illegible]46.[illegible]	[illegible]46.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]0,000	1 to 6	15[illegible],360	284,565	[illegible]46.4	[illegible]46.[illegible]	[illegible]46.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]50,000	Closed	0	550,000[3]	[illegible]50.[illegible]	[illegible]50.[illegible]	[illegible]51.0	[illegible]50.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]50,000	Closed	0	650,000[3]	[illegible]55.9	[illegible]55.8	[illegible]54.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]50,000	Closed	0	750,000[3]	[illegible]57.5	[illegible]57.5	[illegible]57.[illegible]	[illegible]57.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]50,000	Closed	0	850,000[3]	660.8	661.0	661.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Flow in bays 7 and 8 adjusted for fishway [illegible]

[2] Flow in bays 1 and [illegible] adjusted for skimming fl[illegible] [illegible] fishway [illegible]ion

[3] Free flow

TABLE E

WATER-SURFACE ELEVATIONS

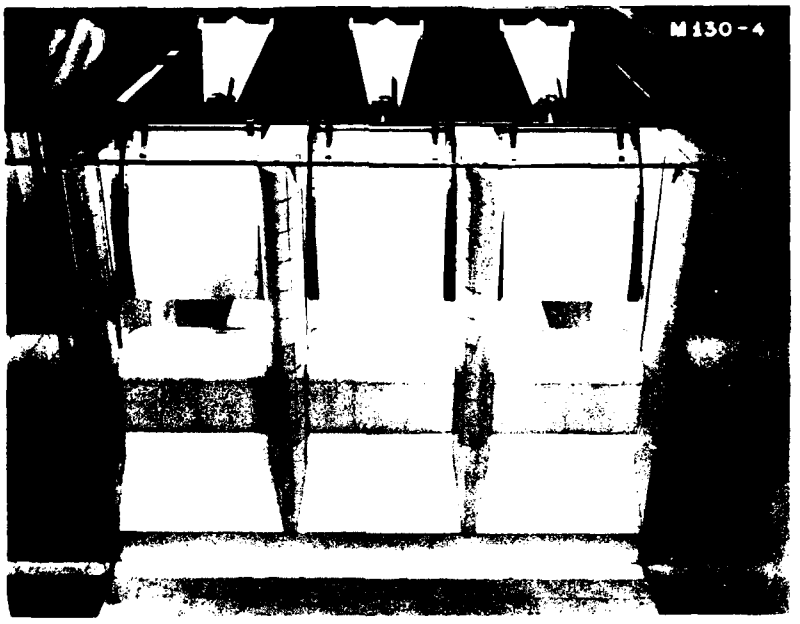
Final [illegible] excavation

Water-surface elevations in feet - MSL													
		Spillway	Intake	Dry Dock		Flashway Entrance				Powerhouse			Pool
Q	H	E-1	E-	E-	E-4	E-5 North	Unit 5	Unit 4	Unit 3	Unit 2	Unit 1	Unit 6	E-1
3.0	[illegible]	[illegible].1	[illegible].4	63[illegible].7	63[illegible].6	[illegible]38.3	633.1	633.0	[illegible]3[illegible].4	[illegible]33.0	[illegible]33[illegible]	[illegible]33.2	[illegible]3[illegible].4
7.9	[illegible]3[illegible].4	[illegible]3[illegible].2	[illegible]37.4	[illegible]37.7	637.1	[illegible]3[illegible].2	[illegible]38.3	[illegible]3[illegible]	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4
3.2	[illegible]3[illegible].2	[illegible]3[illegible].7	[illegible]3[illegible].4	[illegible]3[illegible].1	[illegible]3[illegible].4	[illegible]3[illegible].3	[illegible]3[illegible].2	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4
3.2	[illegible]38.3	[illegible]3[illegible].4	[illegible]3[illegible].6	[illegible]3[illegible].0	637.4	[illegible]38.3	[illegible]38.2	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4
3.7	[illegible]3[illegible].7	[illegible]3[illegible].2	[illegible]3[illegible].3	[illegible]3[illegible].7	[illegible]3[illegible].4	[illegible]3[illegible].7	[illegible]3[illegible].7	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4
3.6	[illegible]3[illegible].7	[illegible]3[illegible].7	[illegible]3[illegible].7	[illegible]3[illegible].7	[illegible]3[illegible].4	[illegible]3[illegible].7	[illegible]3[illegible].7	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4
3.8	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].1	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].2	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4
3.7	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].2	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4	[illegible]3[illegible].4
0.4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].2	[illegible]4[illegible].3	[illegible]4[illegible].3	[illegible]3[illegible].2	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].1	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.5	[illegible]4[illegible].4	[illegible]4[illegible].3	[illegible]4[illegible].1	[illegible]3[illegible].7	[illegible]4[illegible].3	[illegible]3[illegible].9	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.7	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	6[illegible].7	[illegible]4[illegible].3	[illegible]3[illegible].7	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.7	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	63[illegible].7	[illegible]3[illegible].3	[illegible]3[illegible].4	[illegible]4[illegible].4	[illegible]3[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.8	[illegible]4[illegible].1	[illegible]4[illegible].4	640.7	[illegible]4[illegible].1	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.5	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].3	[illegible]4[illegible].3	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.5	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].2	[illegible]4[illegible].3	[illegible]4[illegible].2	[illegible]4[illegible].8	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.5	[illegible]4[illegible].3	[illegible]4[illegible].3	[illegible]4[illegible].7	[illegible]4[illegible].3	641.7	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.4	[illegible]4[illegible].7	[illegible]4[illegible].4	[illegible]4[illegible].1	[illegible]4[illegible].3	[illegible]4[illegible].3	[illegible]4[illegible].8	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
0.4	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	640.4	[illegible]4[illegible].1	[illegible]4[illegible].8	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
1.8	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].0	[illegible]4[illegible].0	[illegible]4[illegible].9	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
2.2	[illegible]4[illegible].1	[illegible]4[illegible].4	[illegible]4[illegible].3	[illegible]4[illegible].0	[illegible]4[illegible].4	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	7[illegible].4
2.2	[illegible]4[illegible].3	[illegible]4[illegible].1	[illegible]4[illegible].2	[illegible]4[illegible].4	[illegible]4[illegible].0	[illegible]4[illegible].4	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
2.2	[illegible]4[illegible].6	[illegible]4[illegible].3	[illegible]4[illegible].0	[illegible]4[illegible].4	[illegible]4[illegible].0	[illegible]4[illegible].1	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
2.4	647.6	[illegible]4[illegible].3	[illegible]4[illegible].7	[illegible]4[illegible].2	[illegible]4[illegible].2	[illegible]4[illegible].1	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
2.4	[illegible]47.6	[illegible]4[illegible].3	[illegible]4[illegible].4	647.0	[illegible]4[illegible].1	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
2.3	[illegible]5[illegible].3	[illegible]4[illegible].7	[illegible]4[illegible].7	[illegible]5[illegible].3	[illegible]4[illegible].7	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
2.7	[illegible]5[illegible].3	[illegible]5[illegible].0	[illegible]4[illegible].6	[illegible]5[illegible].8	[illegible]4[illegible].3	[illegible]4[illegible].7	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
3.0	660.4	[illegible]5[illegible].3	[illegible]5[illegible].3	[illegible]5[illegible].5	[illegible]5[illegible].7	[illegible]4[illegible].5	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].4
3.6	[illegible]6[illegible].4	[illegible]6[illegible].4	[illegible]5[illegible].3	[illegible]4[illegible].3	[illegible]5[illegible].3	[illegible]4[illegible].0	[illegible]4[illegible].3	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4	[illegible]4[illegible].3	[illegible]4[illegible].4	[illegible]4[illegible].4

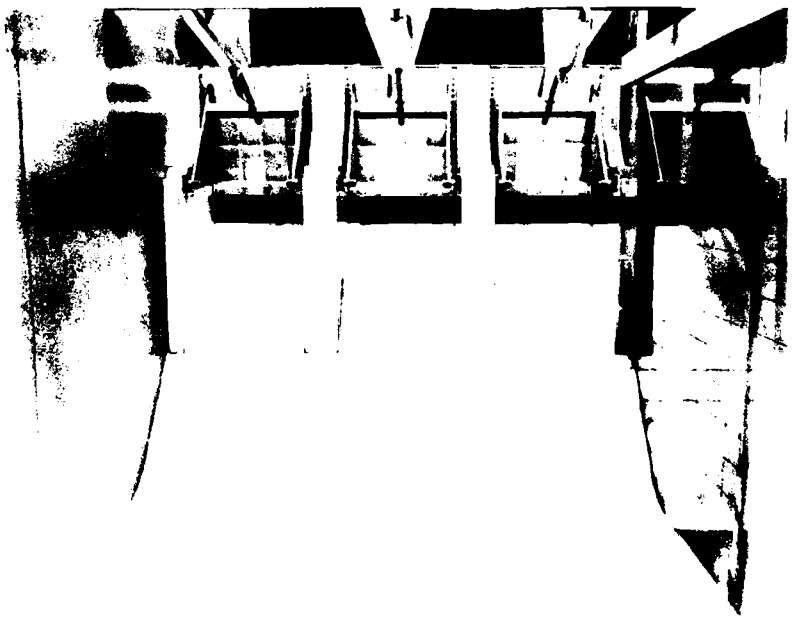
NOTES: 1. Fish ladder discharge [illegible] of the river flow [illegible] and including 40,000 cfs; Flashway closed for higher flows.

for flashway operation

2. Gage locations shown on plates 6 and 7.



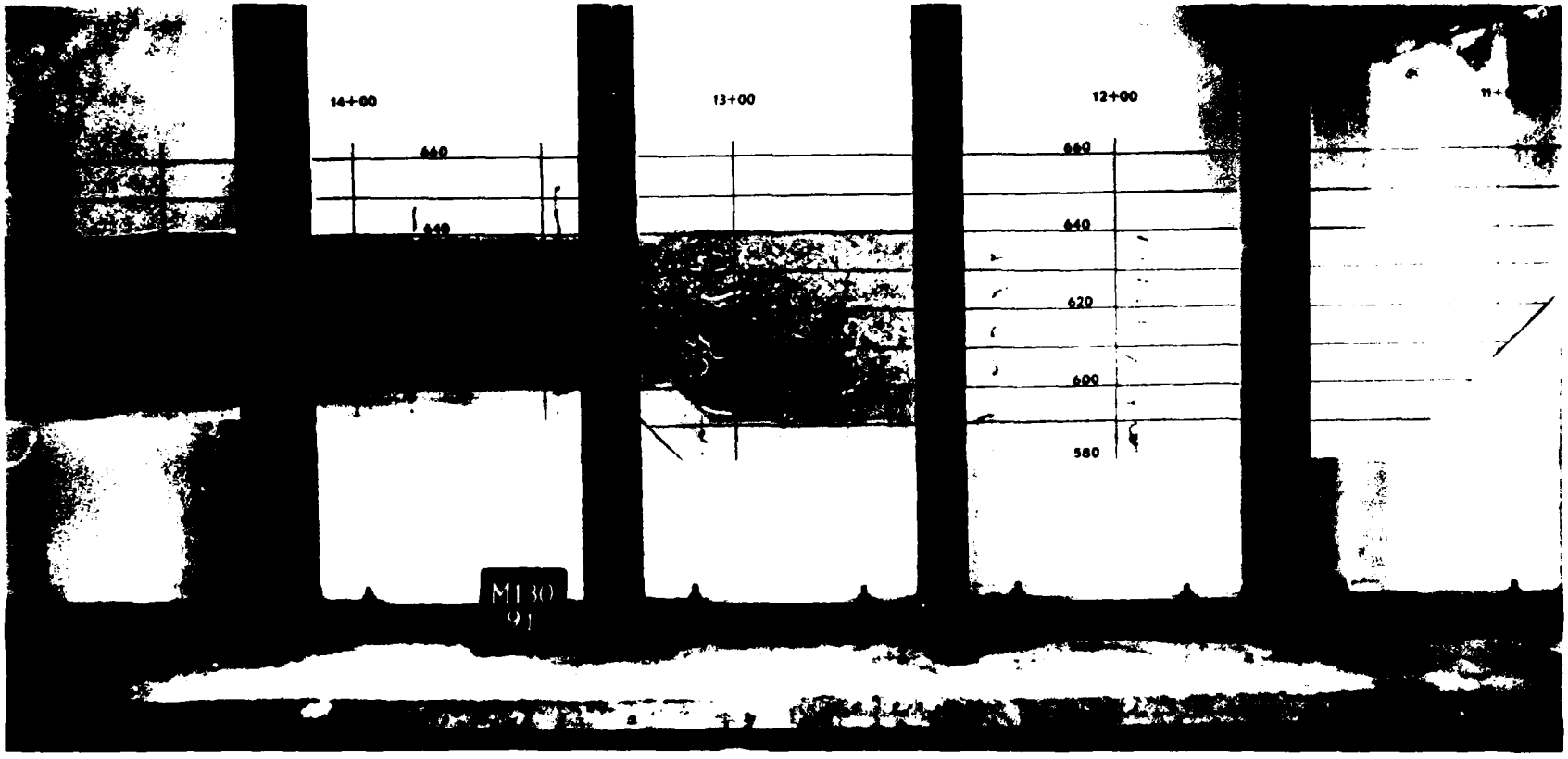
Looking downstream



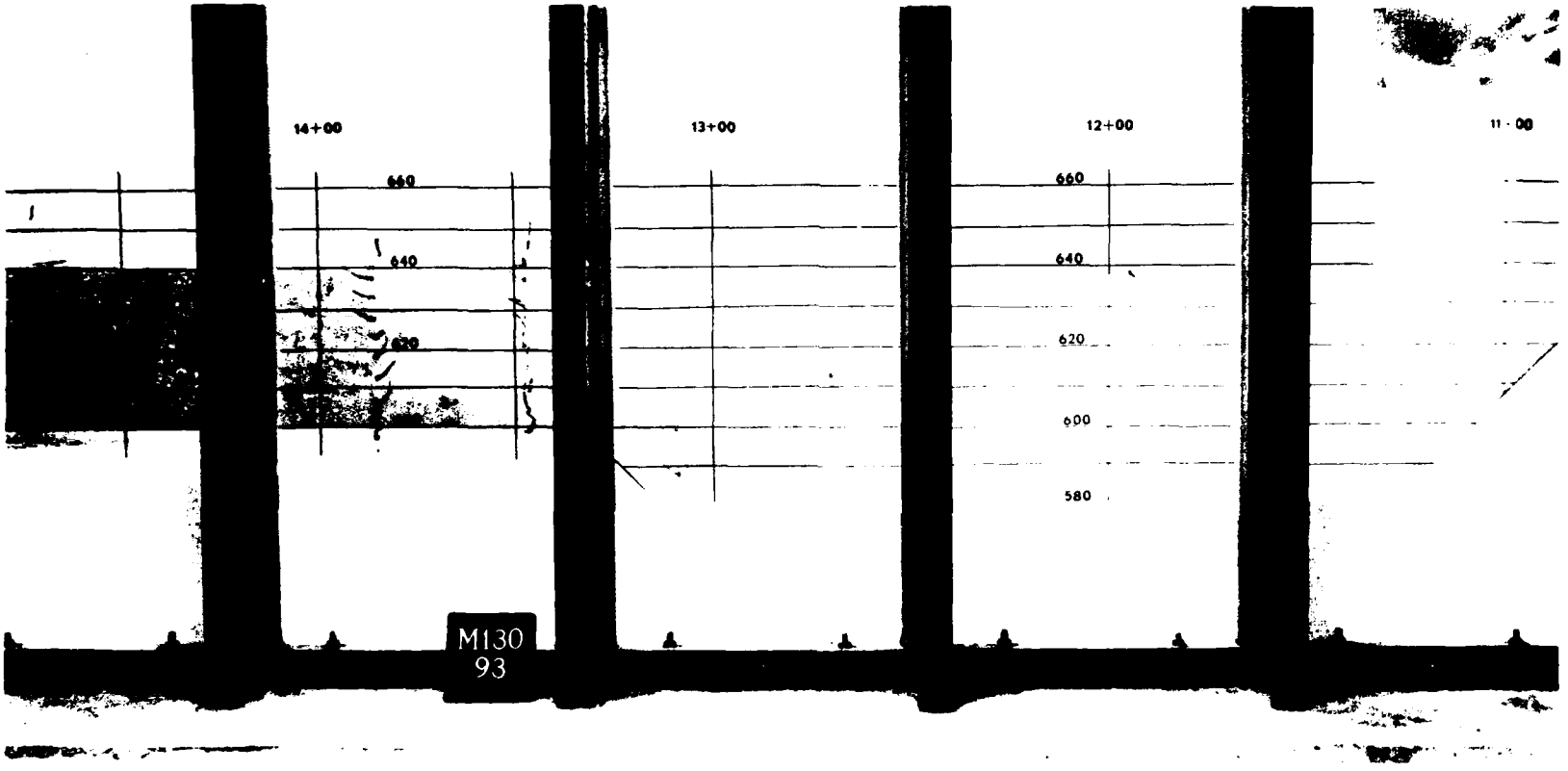
Looking upstream

Photograph 1. Original design (plan A) crest, piers, and stilling basin in 1:42.47-scale spillway model.

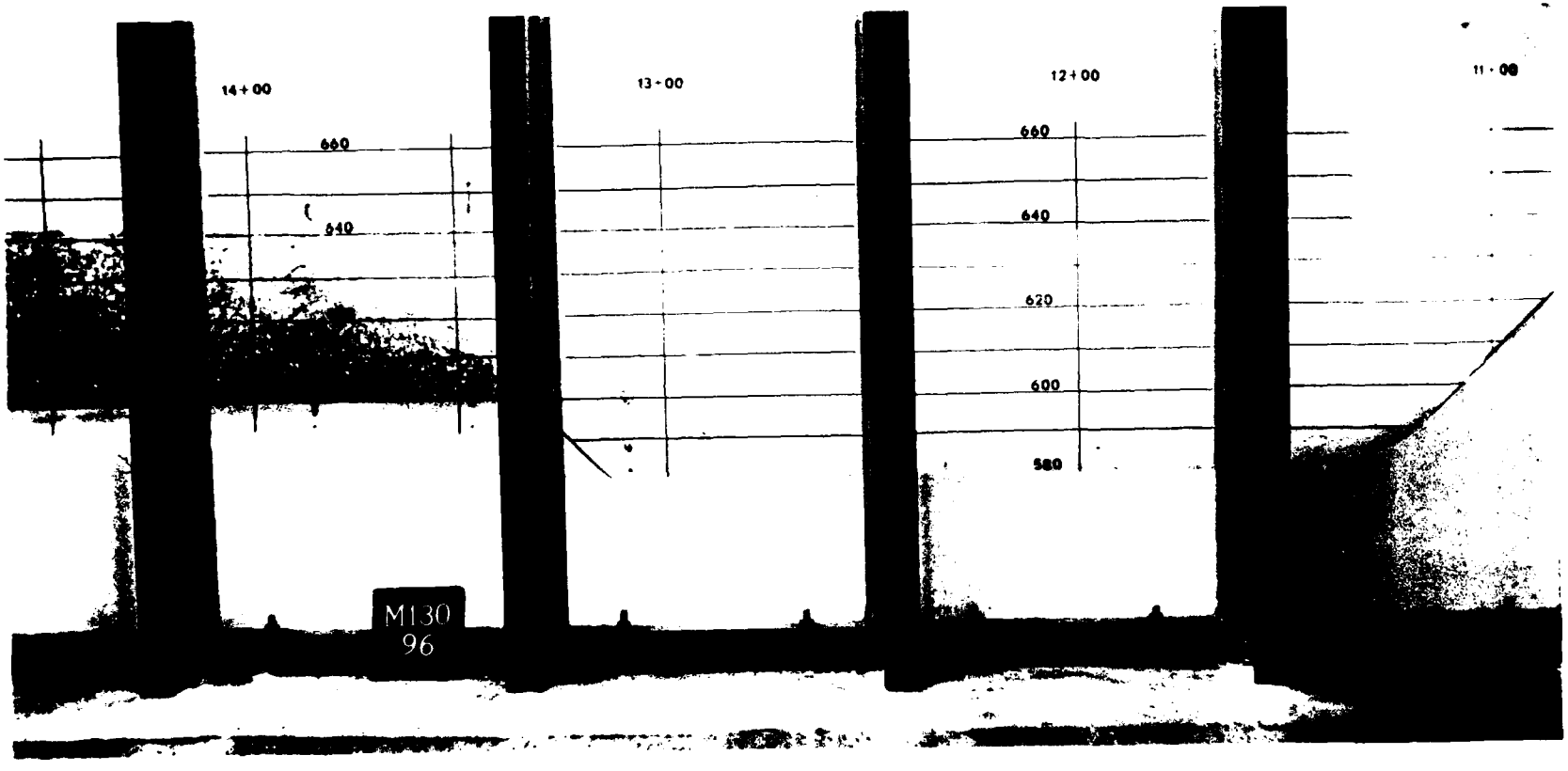
Photograph 2. Flow conditions at spillway; free flow, pool elevation 745.9, discharge 106,250 cfs per bay (850,000 cfs through eight bays).



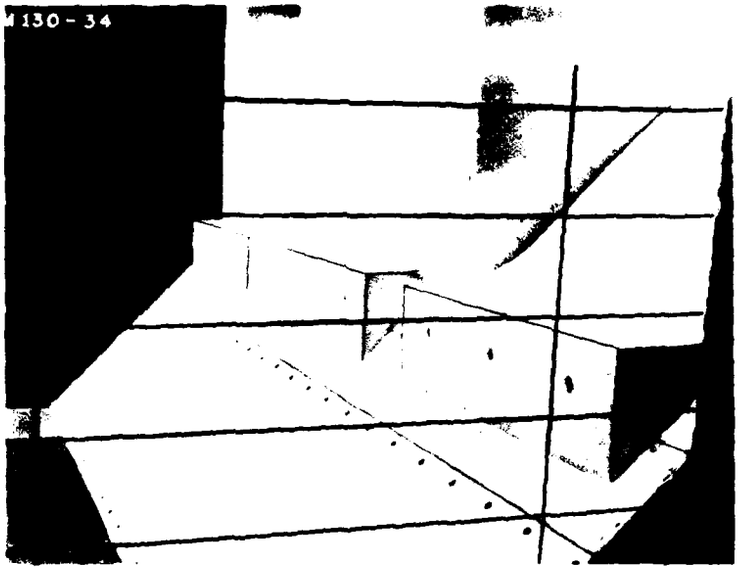
Photograph 3. Flow conditions, plan A spillway and stilling basin, no deflectors. Spillway discharge 5,210 cfs per bay, river discharge 171,000 cfs, tailwater elevation 641.0.



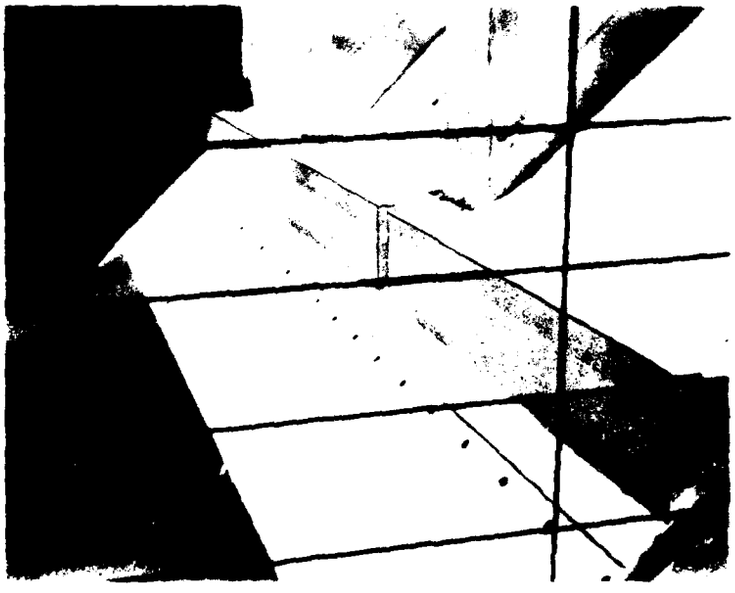
Photograph 4. Flow conditions, plan A spillway and stilling basin, no deflectors. Spillway discharge 10,150 cfs per bay, river discharge 212,000 cfs, tailwater elevation 642.2.



Photograph 5. Flow conditions, plan A spillway and stilling basin, no deflectors. Spillway discharge 15,100 cfs per bay, river discharge 252,000 cfs, tailwater elevation 643.2.

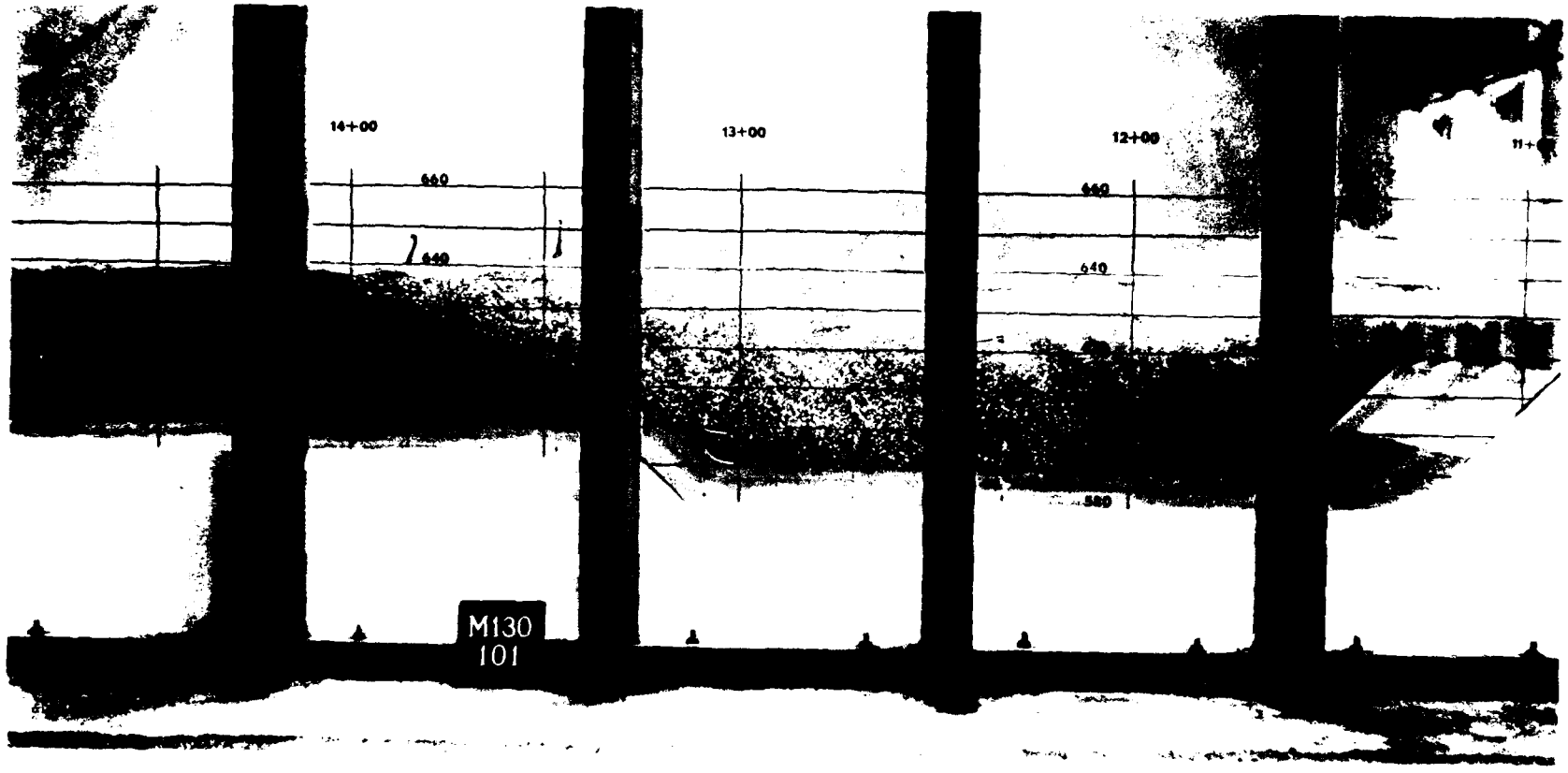


15-foot deflectors, elevation 634

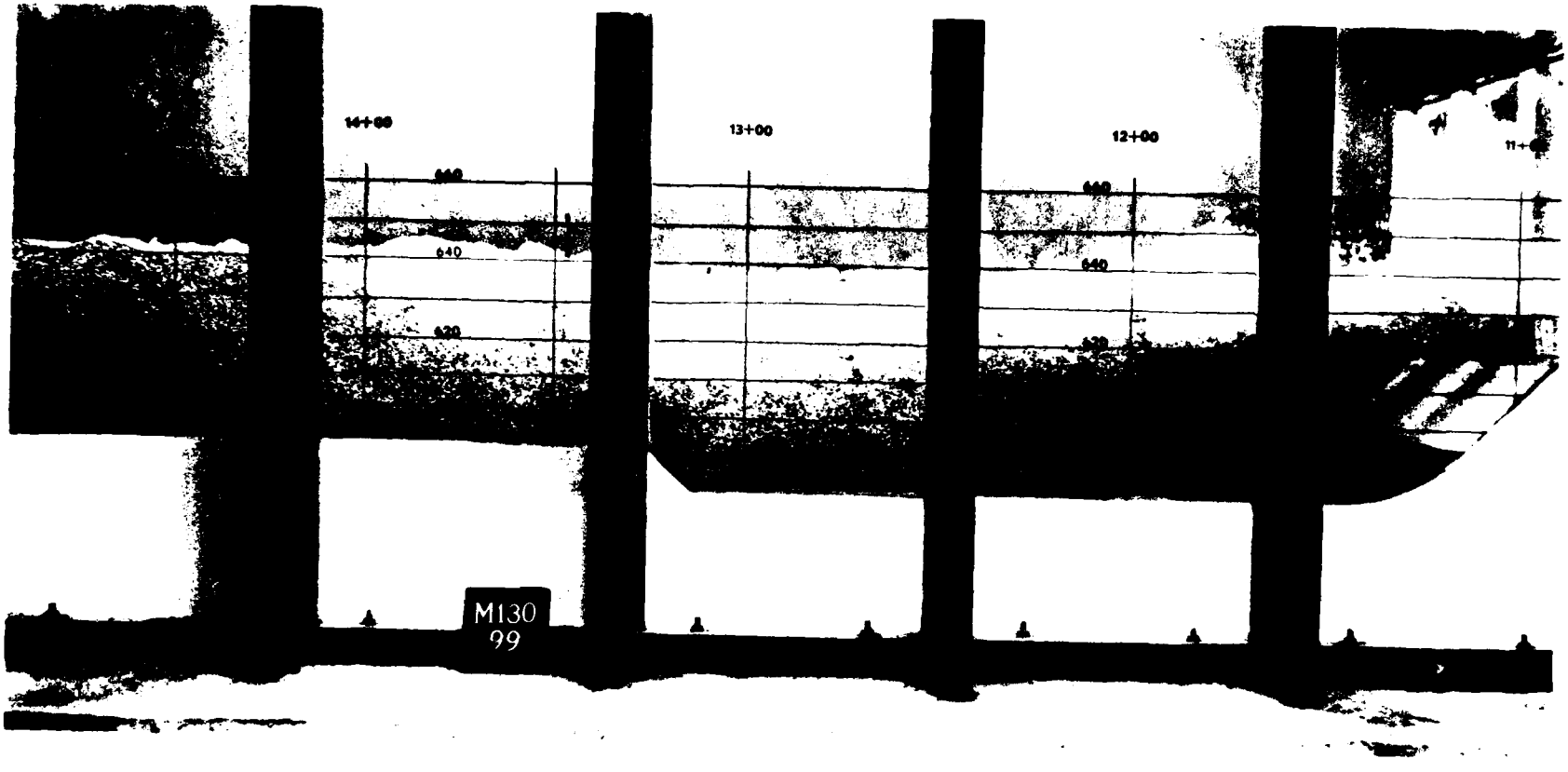


12.5-foot deflectors, elevation 630

Photograph 6. Deflectors on spillway ogee.

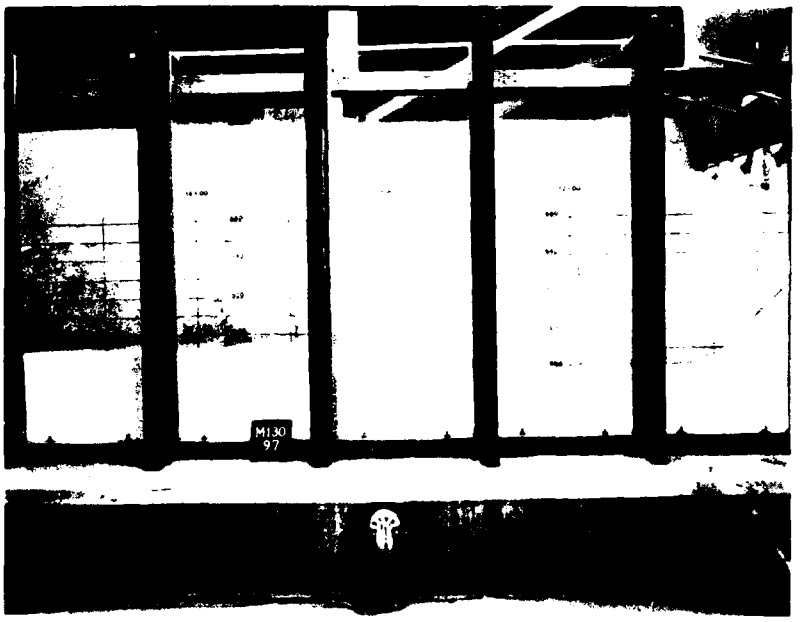


Photograph 7. Flow conditions with 12.5-foot deflectors at elevation 630. Spillway discharge 5,210 cfs per bay, river discharge 171,000 cfs, tailwater elevation 641.0.



Photograph 8. Flow conditions with 12.5-foot deflectors at elevation 630. Spillway discharge 10,150 cfs per bay, river discharge 212,000 cfs, tailwater elevation 642.2.

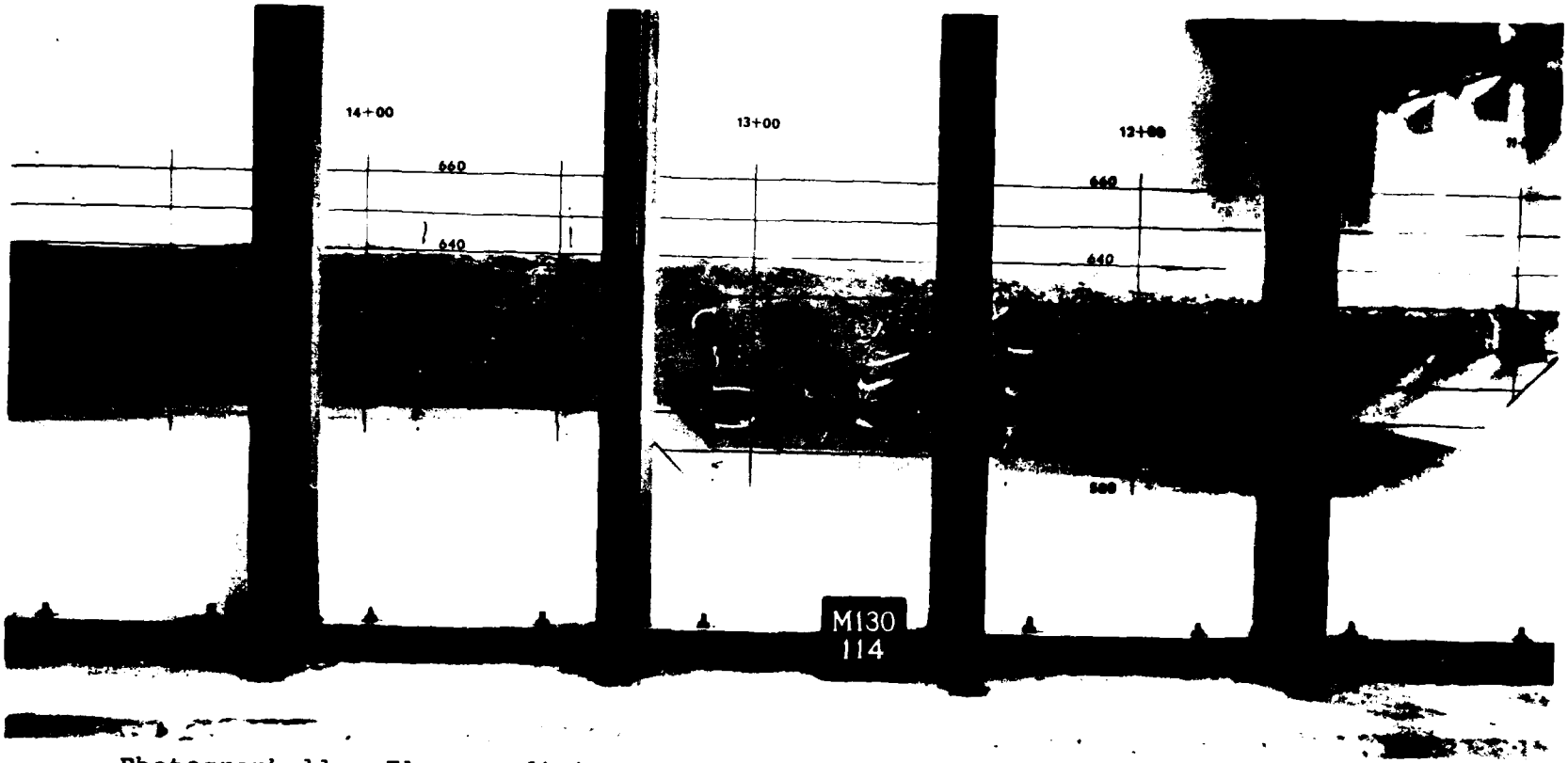
Photograph 9. Flow conditions with 12.5-foot deflectors at elevation 630. Spillway discharge 15,100 cfs per bay, river discharge 252,000 cfs, tailwater elevation 643.5.



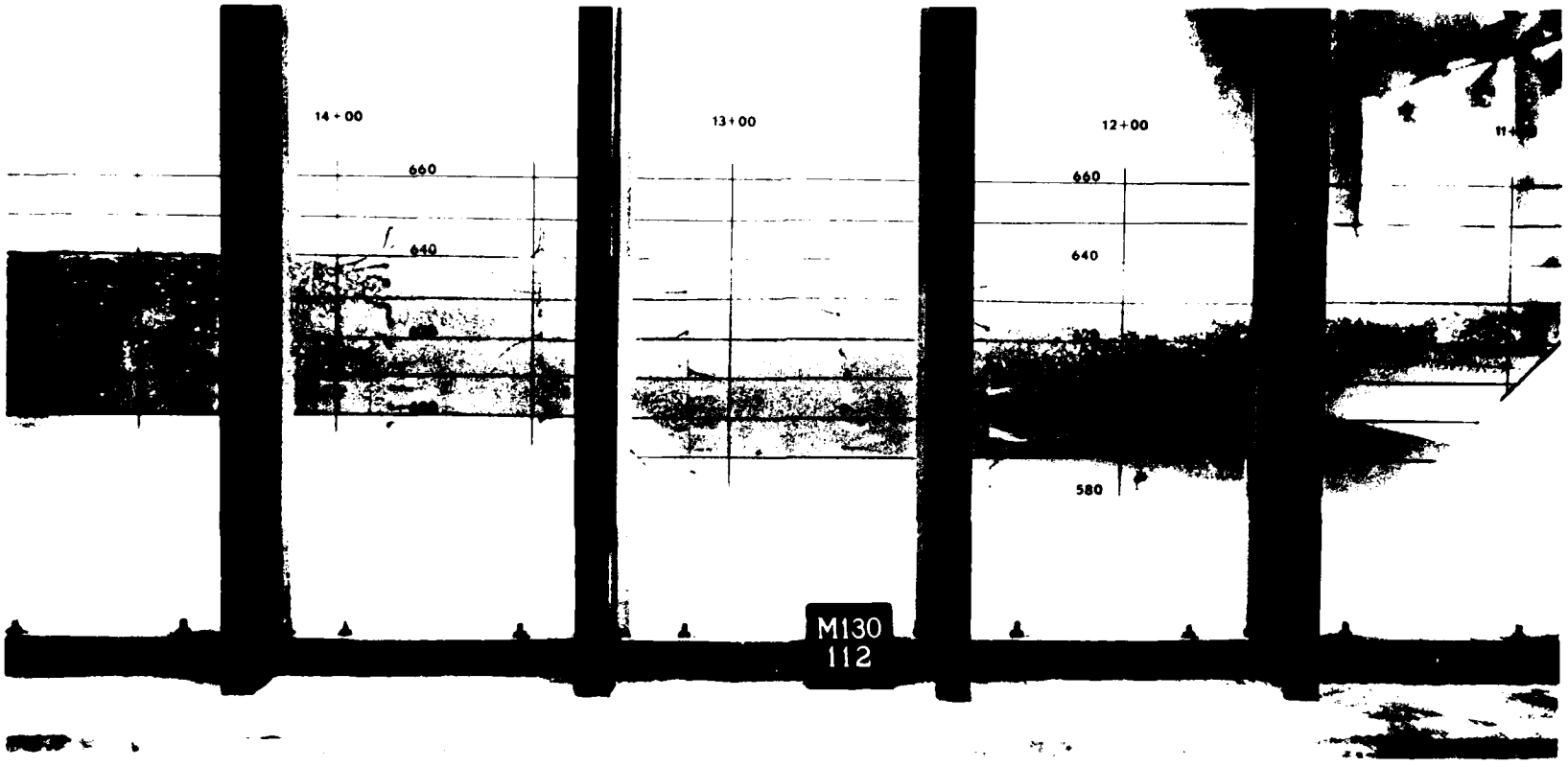
Without deflector

With 12.5-foot deflector at elevation 630

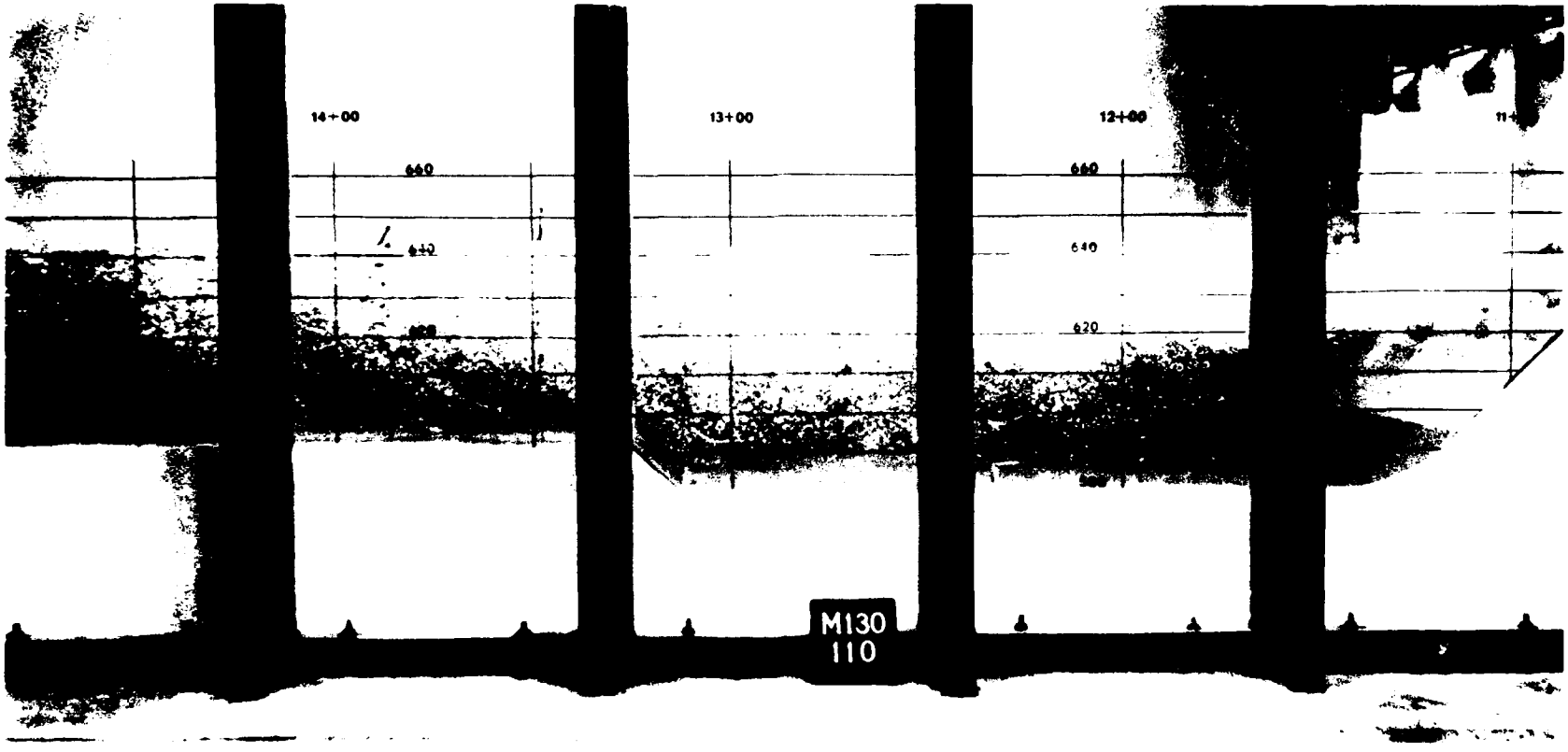
Photograph 10. Flow conditions with standard project flood. Spillway discharge 37,170 cfs per bay, river discharge 420,000 cfs, tailwater elevation 649.4.



Photograph 11. Flow conditions with 12.5-foot deflectors at elevation 620 and plan H dentates. Spillway discharge 5,210 cfs per bay, river discharge 171,000 cfs, tailwater 641.0.

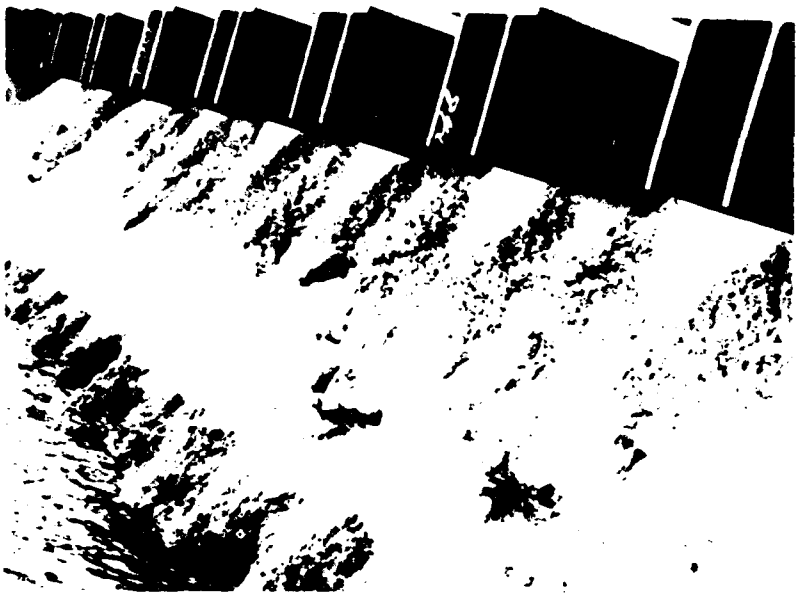


Photograph 12. Flow conditions with 12.5-foot deflectors at elevation 630 and plan H dentates. Spillway discharge 10,150 cfs per bay, river discharge 212,000 cfs, tailwater elevation 642.2.



Photograph 13. Flow conditions with 12.5-foot deflectors at elevation 630 and plan H dentates. Spillway discharge 15,100 cfs per bay, river discharge 252,000 cfs, tailwater elevation 643.2.

Looking upstream



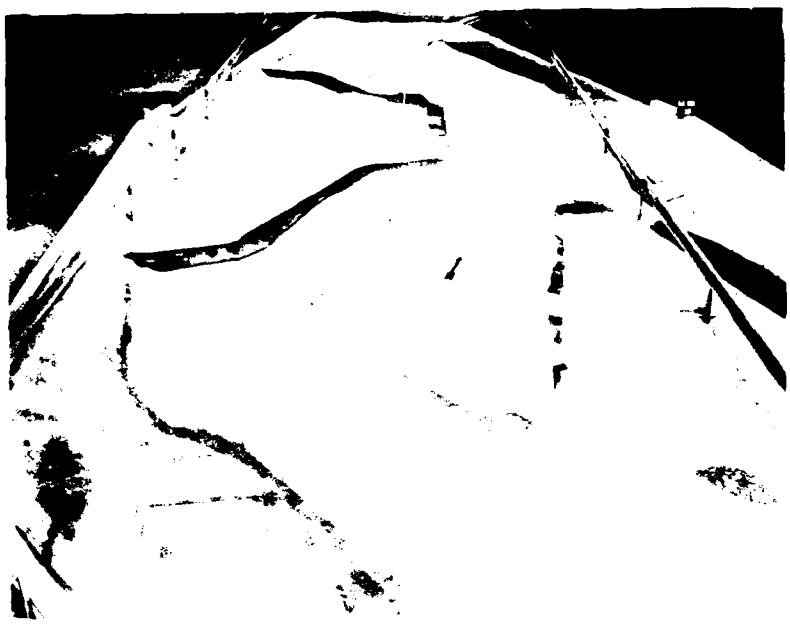
Oblique view

Photograph 14. Damaged concrete adjacent to dentates on Lower Monumental spillway after 1972 flood season.

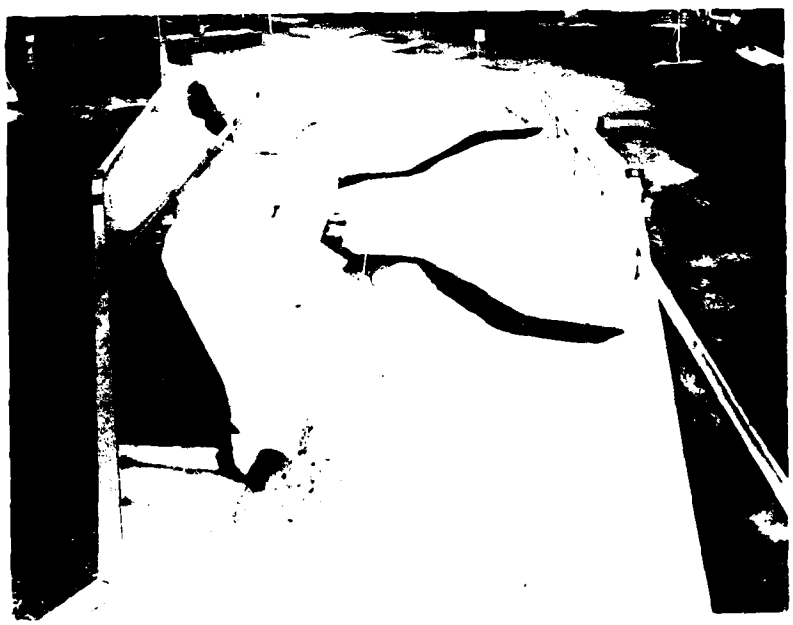
Looking downstream

Looking upstream

Photograph 15. Flow conditions with plan C (recommended design) contractor's dike; river discharge 100,000 cfs, natural tailwater.



Looking downstream



Looking upstream

Photog. aph 16. Plan A first-step cofferdam and diversion channel.

Plan C entrance to diversion channel

Diversion channel with plan K groins

Photograph 17. First-step cofferdam and diversion channel with plan K groins along north (right) bank.

Diversion channel

Diversion channel entrance

Photograph 18. Flow patterns in the first-step cofferdam and diversion channel with plan C entrance, plan A fill, and plan K groins at a river discharge of 200,000 cfs, natural tailwater.

River discharge 50,000 cfs
spillway closed

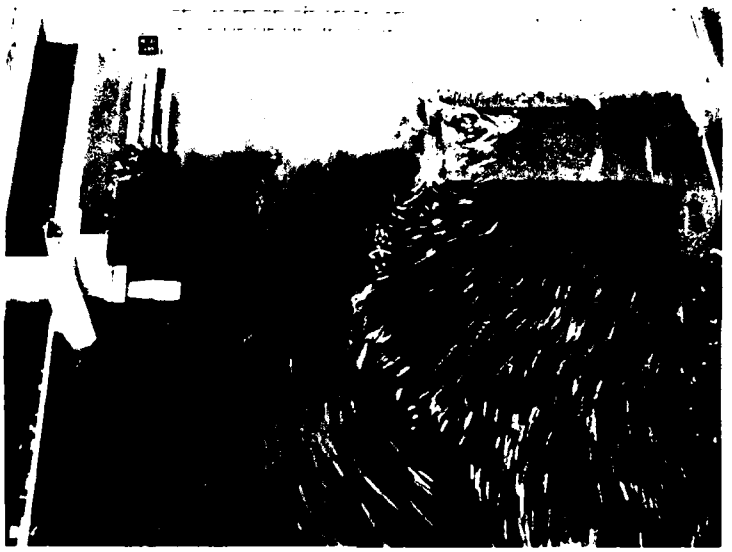
River discharge 100,000 cfs
Units 1 to 3 and bays 1 to 8 operating

Photograph 19. Downstream flow conditions with final design structures and left bank.

Units 1 to 3 operating

Units 1 to 6 operating

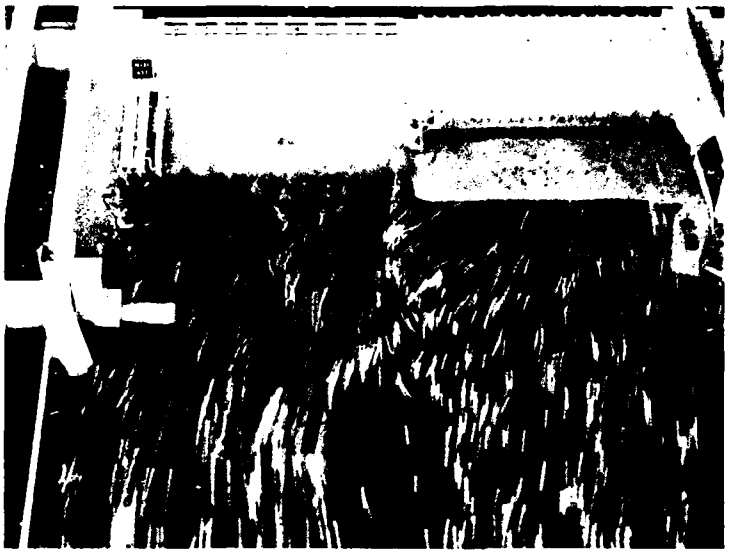
Photograph 20. Downstream flow conditions with final design structures and left bank. River discharge 150,000 cfs, bays 1 to 8 operating uniformly.



Flow patterns downstream from structures

Flow conditions in downstream channel

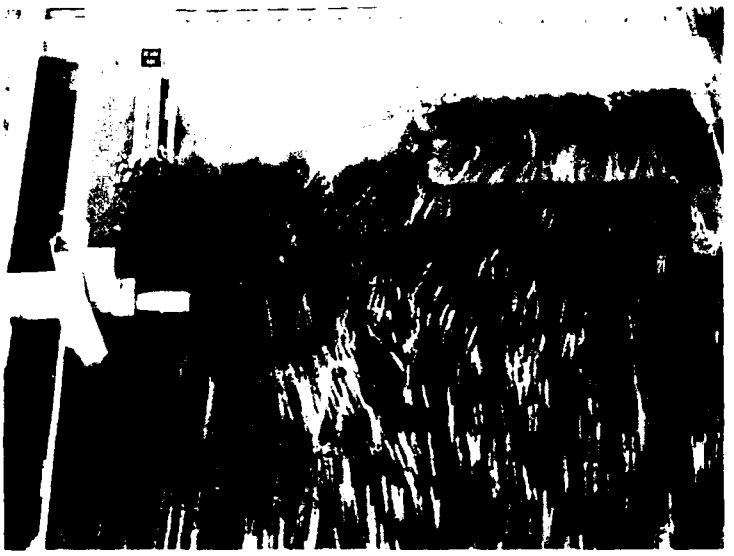
Photograph 21. Flow conditions with final design structures and left bank. River discharge 200,000 cfs, units 1 to 3 and bays 1 to 8 operating.



Flow patterns downstream from structures

Flow conditions in downstream channel

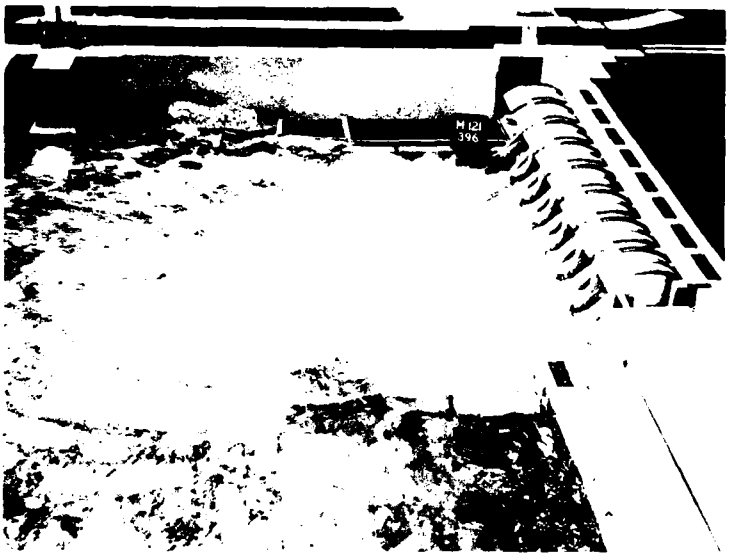
Photograph 22. Flow conditions with final design structures and left bank. River discharge 200,000 cfs, units 1 to 6 and bays 1 to 8 operating.



River discharge 250,000 cfs
Powerhouse units 1 to 6 operating

River discharge 420,000 cfs
Powerhouse units 1 to 3 operating

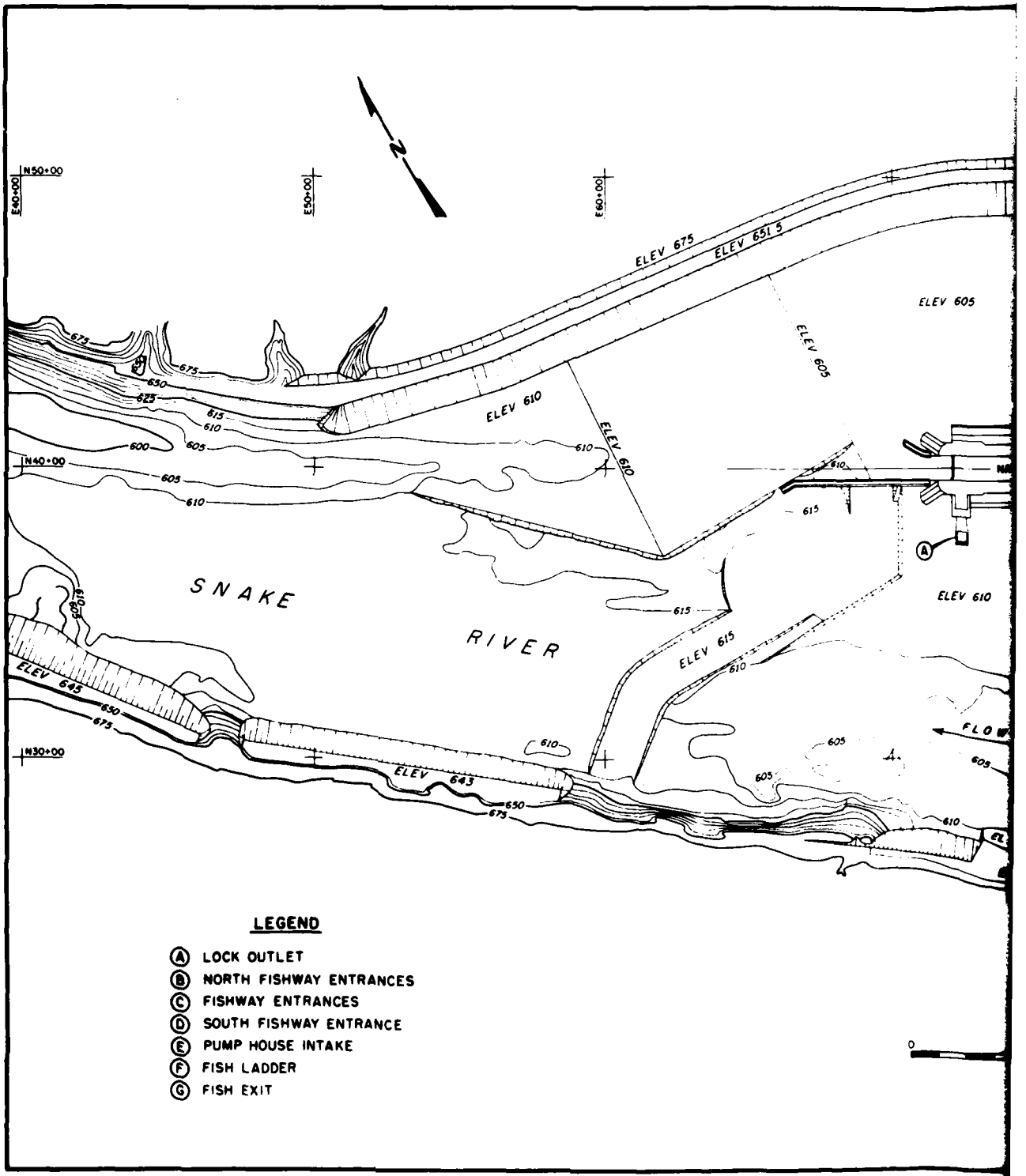
Photograph 23. Flow conditions with final design structures and left bank.

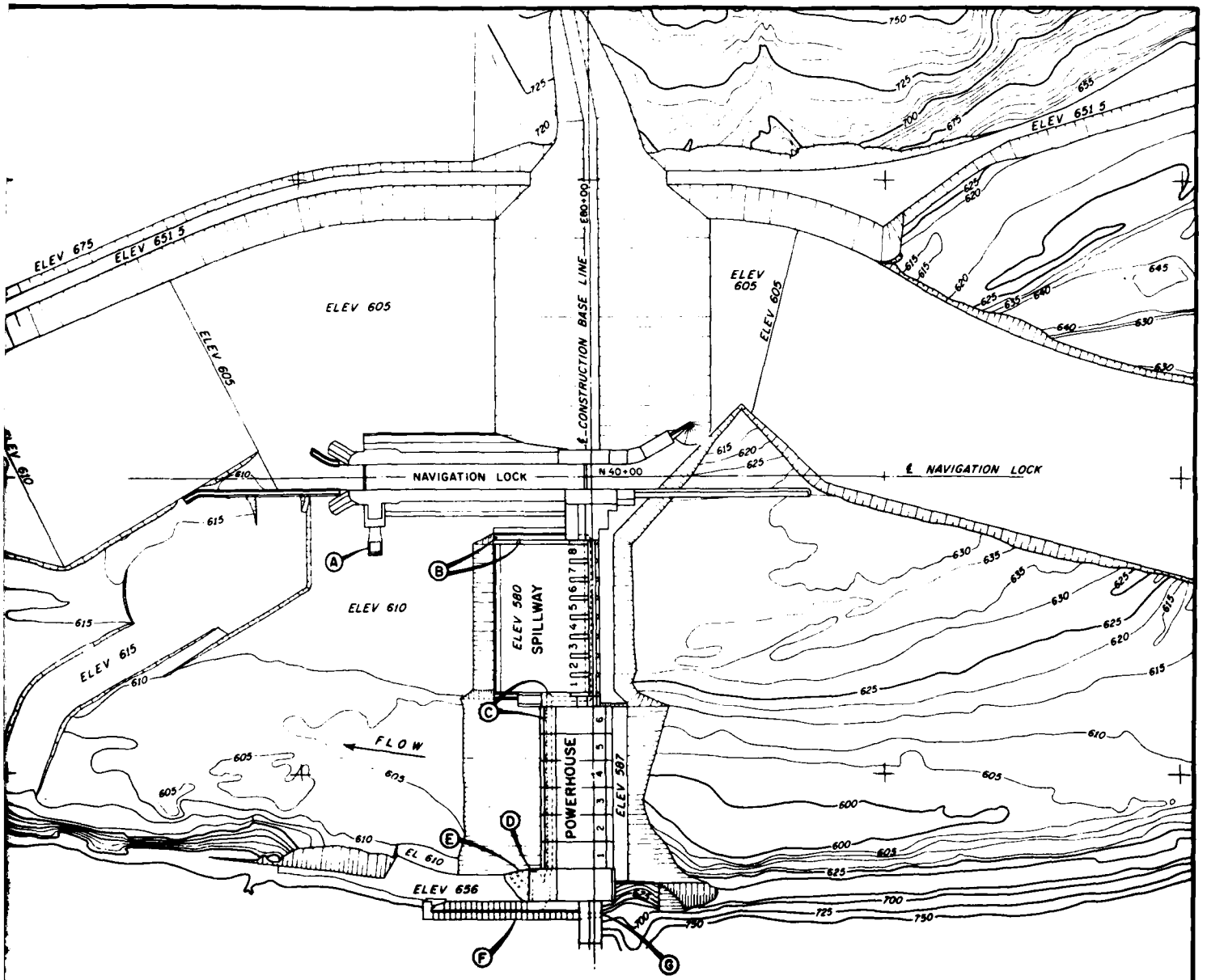


Flow conditions in stilling basin

Flow conditions in downstream channel

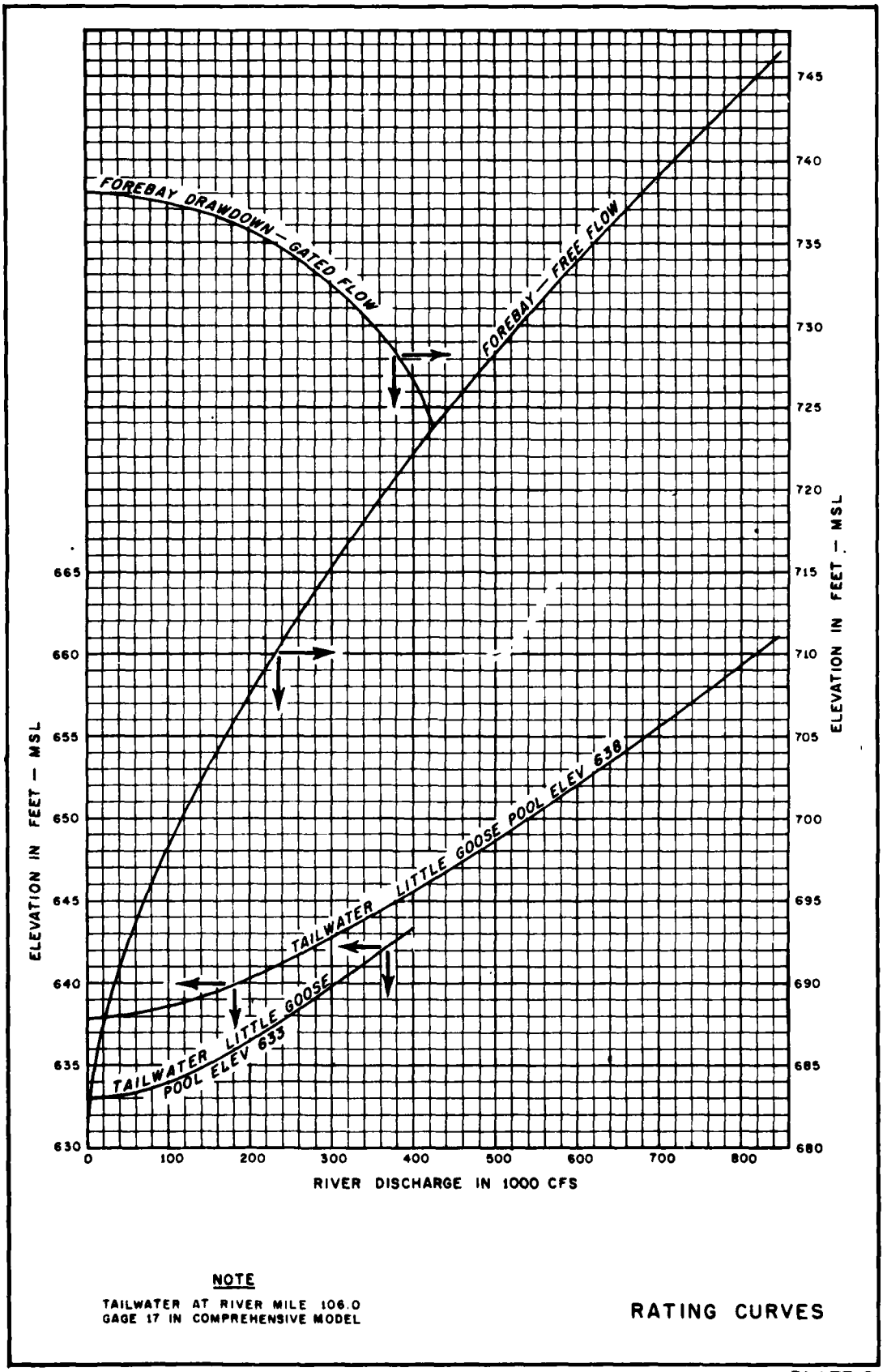
Photograph 24. Flow conditions with final design structures and left bank. River discharge 850,000 cfs, powerhouse closed.


N
N50+00
E40+00
E50+00
E60+00
N40+00
N30+00
ELEV 675
ELEV 651.5
ELEV 605
ELEV 610
ELEV 610
ELEV 605
ELEV 610
ELEV 615
ELEV 615
ELEV 645
ELEV 643
SNAKE
RIVER
FLOW
A
LEGEND
A LOCK OUTLET
B NORTH FISHWAY ENTRANCES
C FISHWAY ENTRANCES
D SOUTH FISHWAY ENTRANCE
E PUMP HOUSE INTAKE
F FISH LADDER
G FISH EXIT



PROJECT LAYOUT

PLATE 1



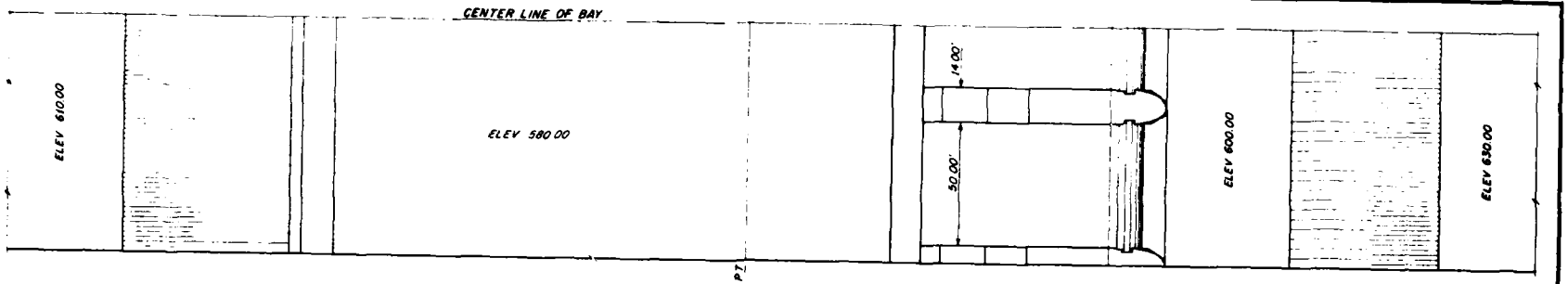
NOTE

TAILWATER AT RIVER MILE 106.0
GAGE 17 IN COMPREHENSIVE MODEL

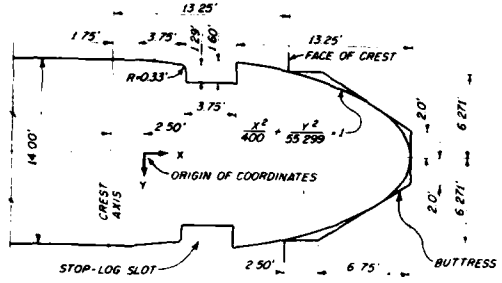
RATING CURVES

PLATE 2

PLATE 3

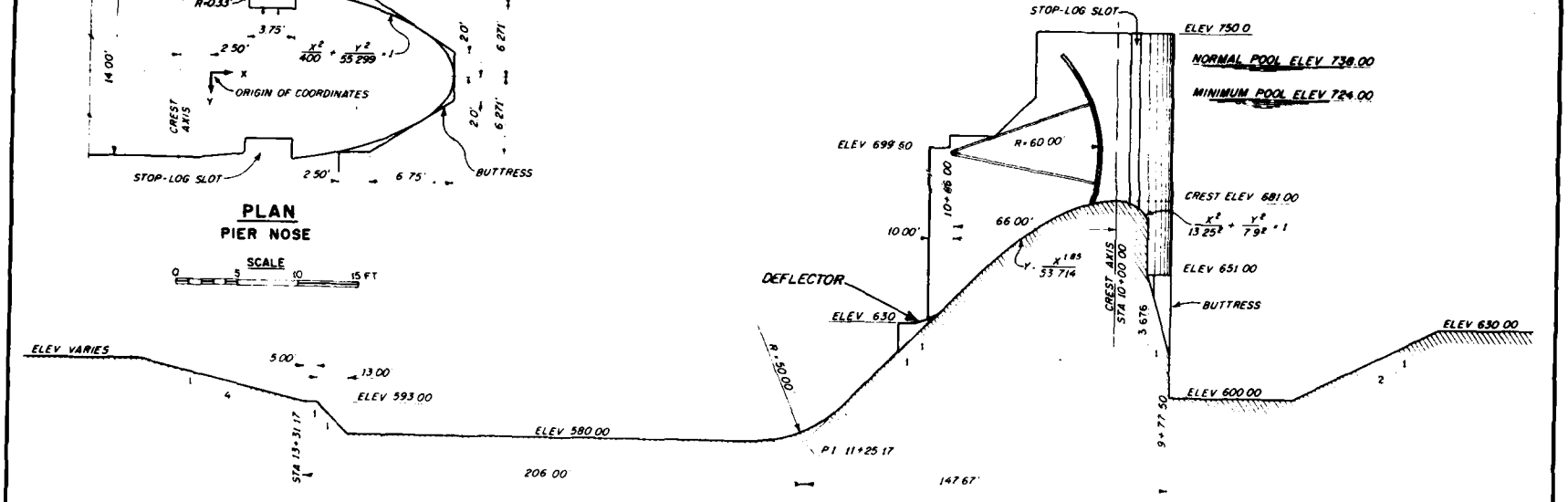


SECTIONAL PLAN



PLAN
PIER NOSE

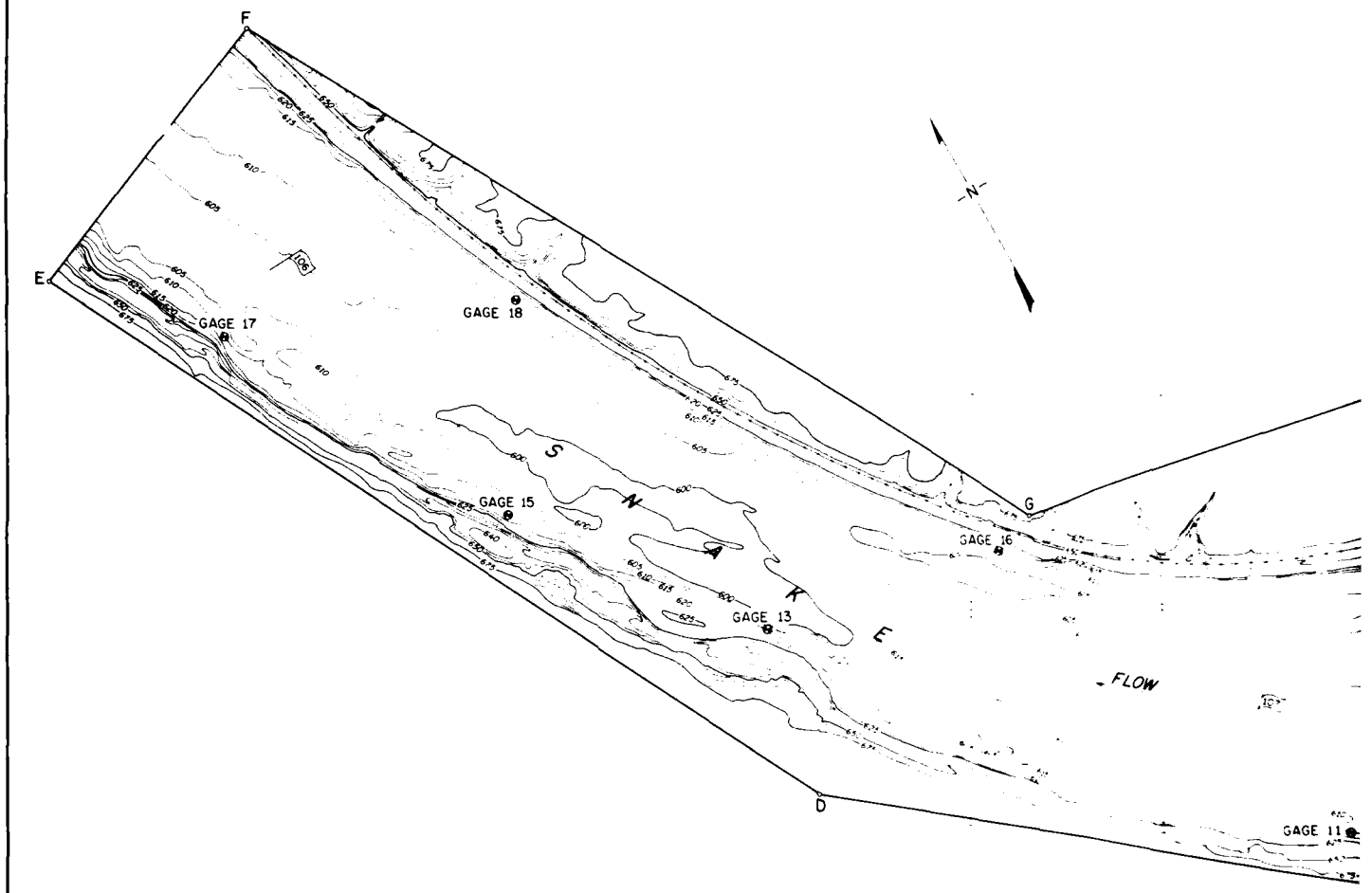
SCALE
0 5 10 15 FT

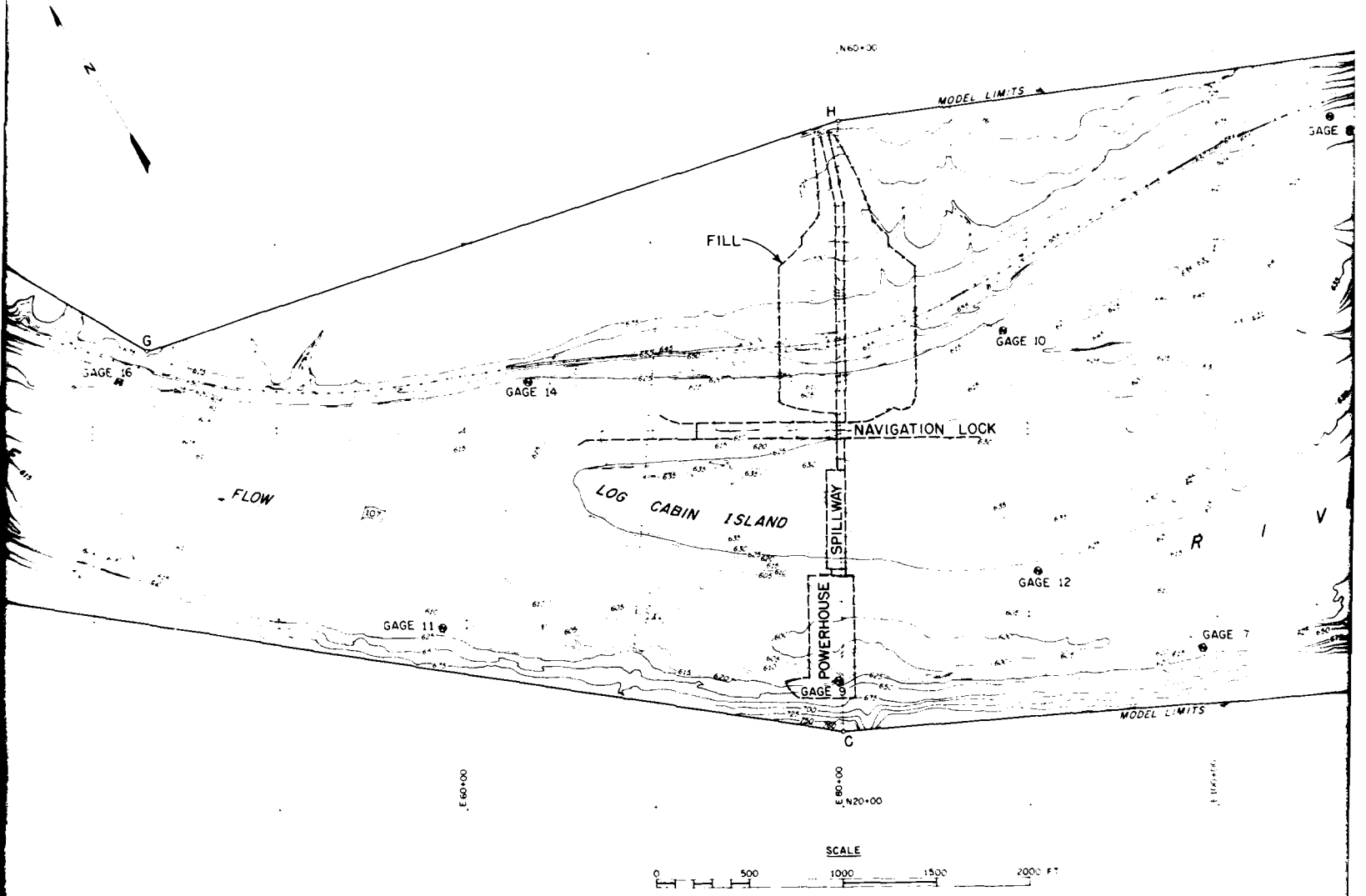


SECTION ALONG CENTER LINE OF BAY

SCALE
0 25 50 75 100 FT

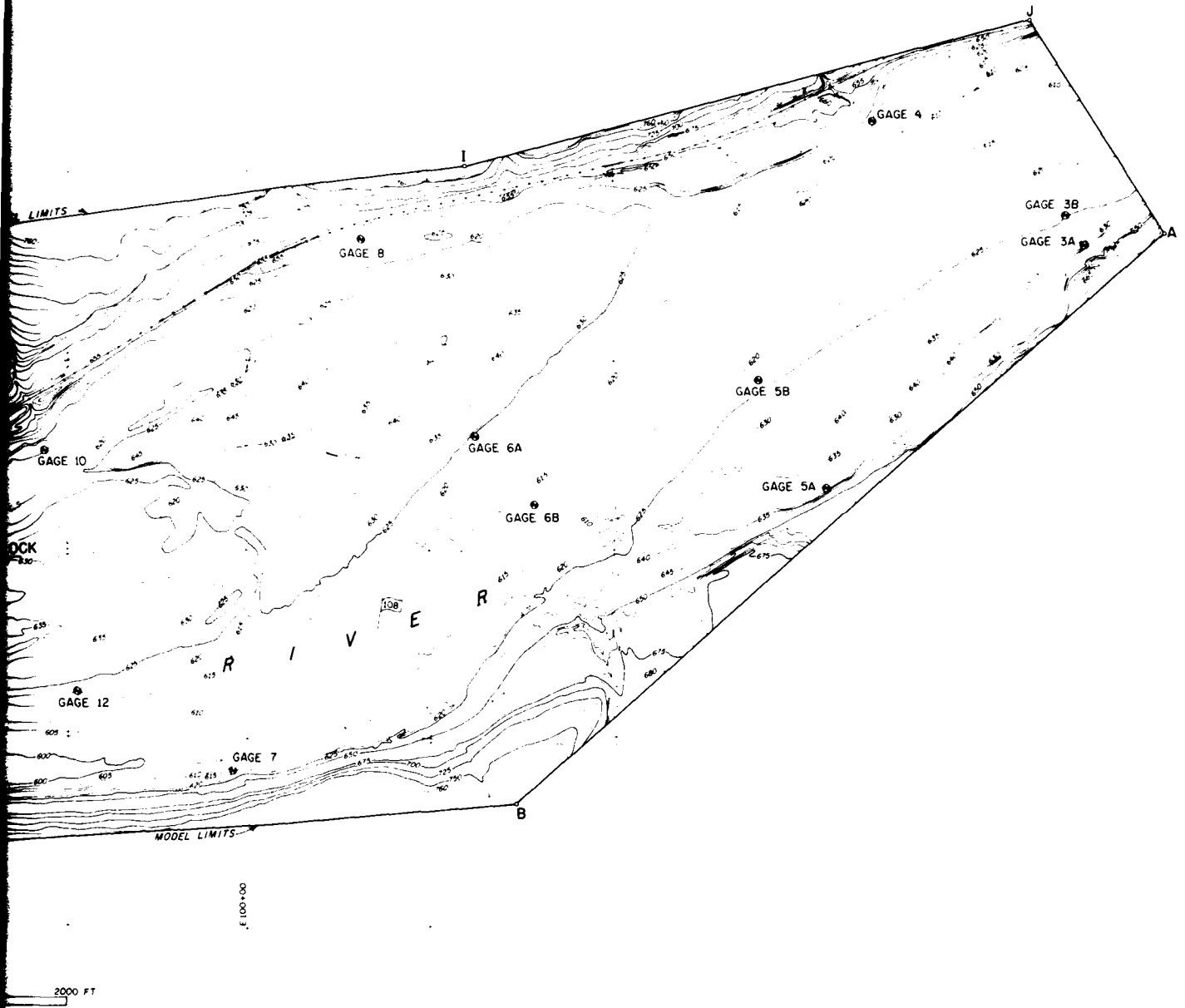
SPILLWAY AND STILLING BASIN


F
E
G
D
N
GAGE 17
GAGE 18
GAGE 15
GAGE 16
GAGE 13
GAGE 11
SNAKE
FLOW



SCALE

0 500 1000 1500 2000 FT



LAYOUT

COMPREHENSIVE MODEL

PLATE 4

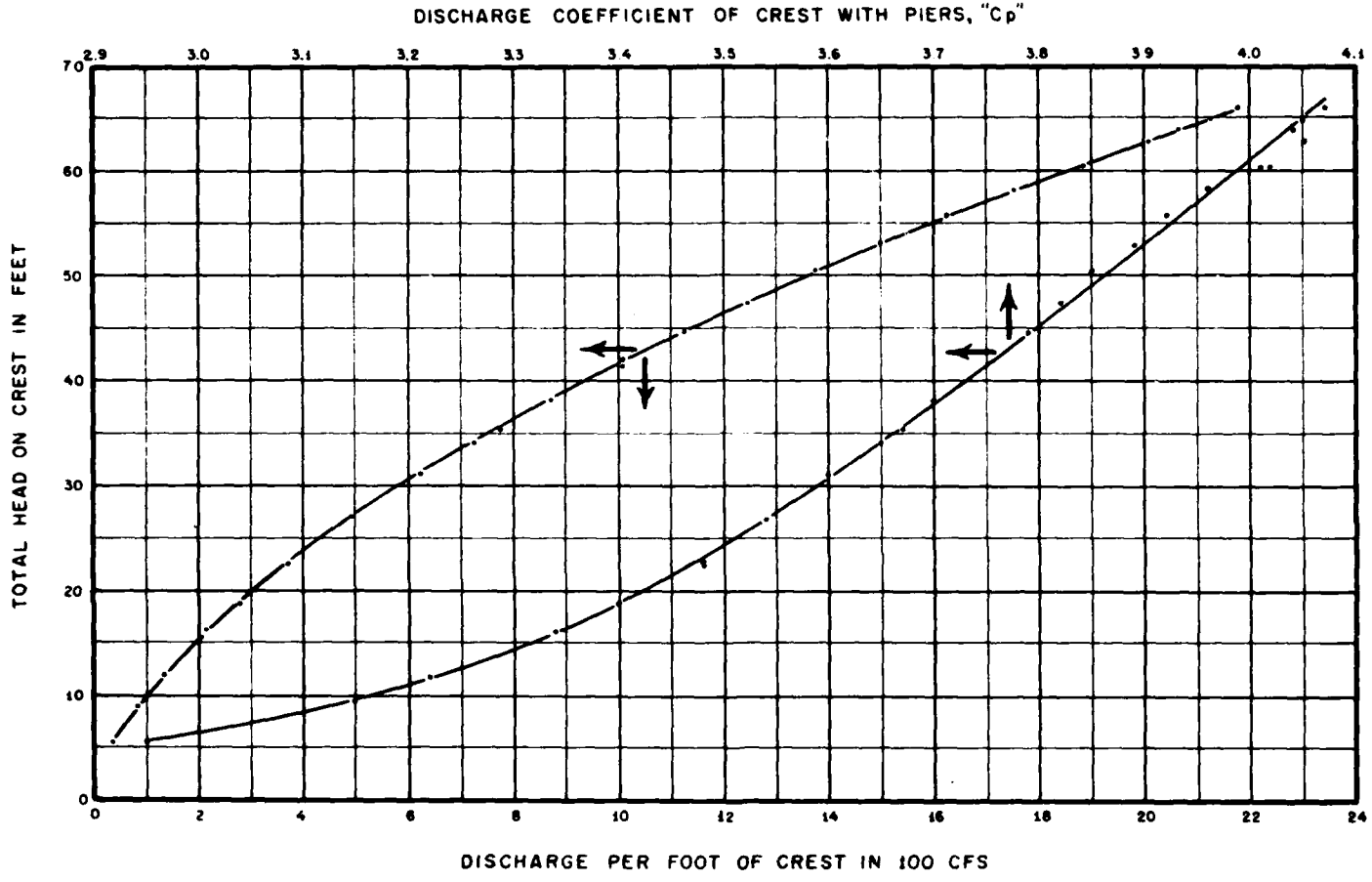


PLATE 5

DISCHARGE AND COEFFICIENT CURVES

FREE FLOW

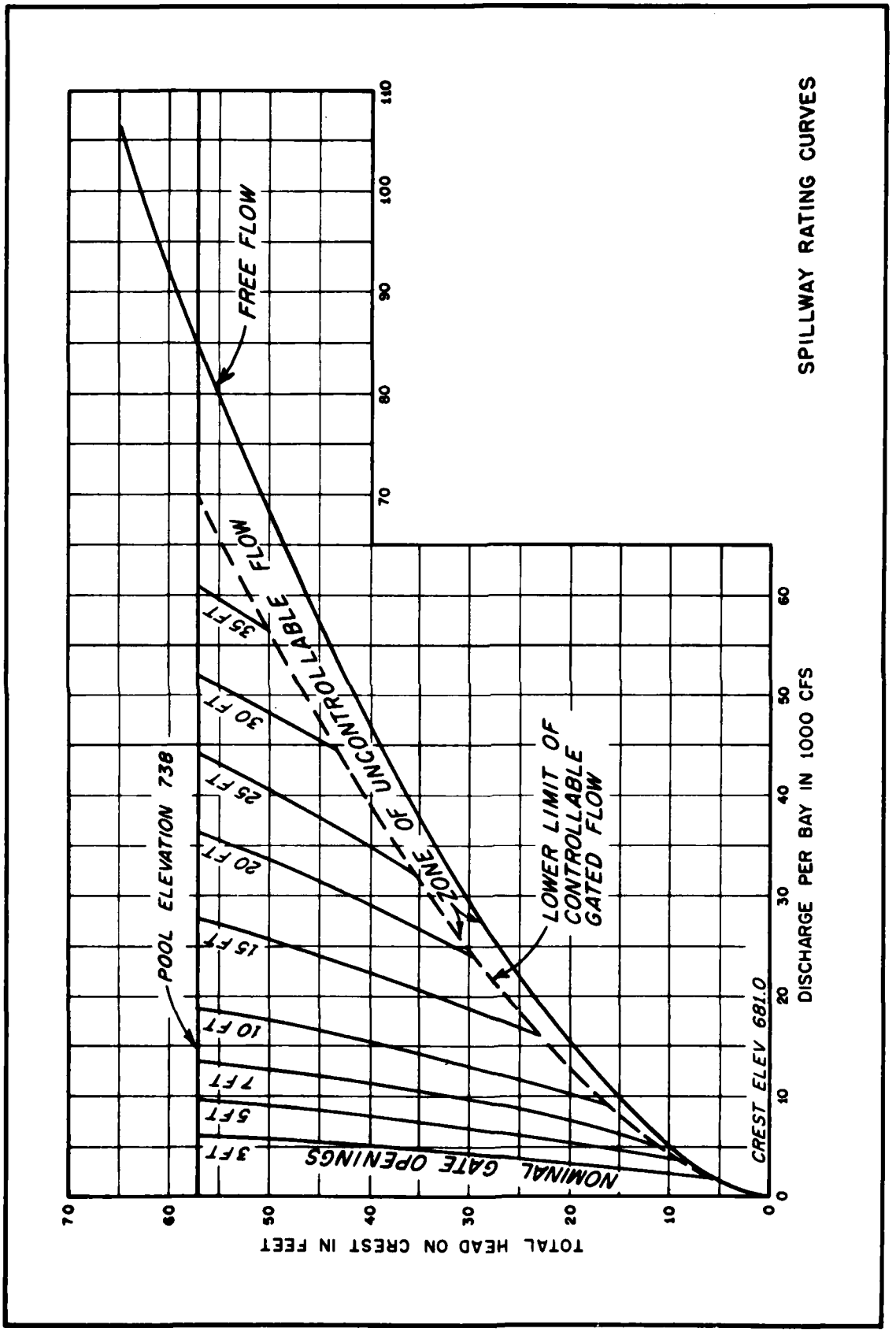
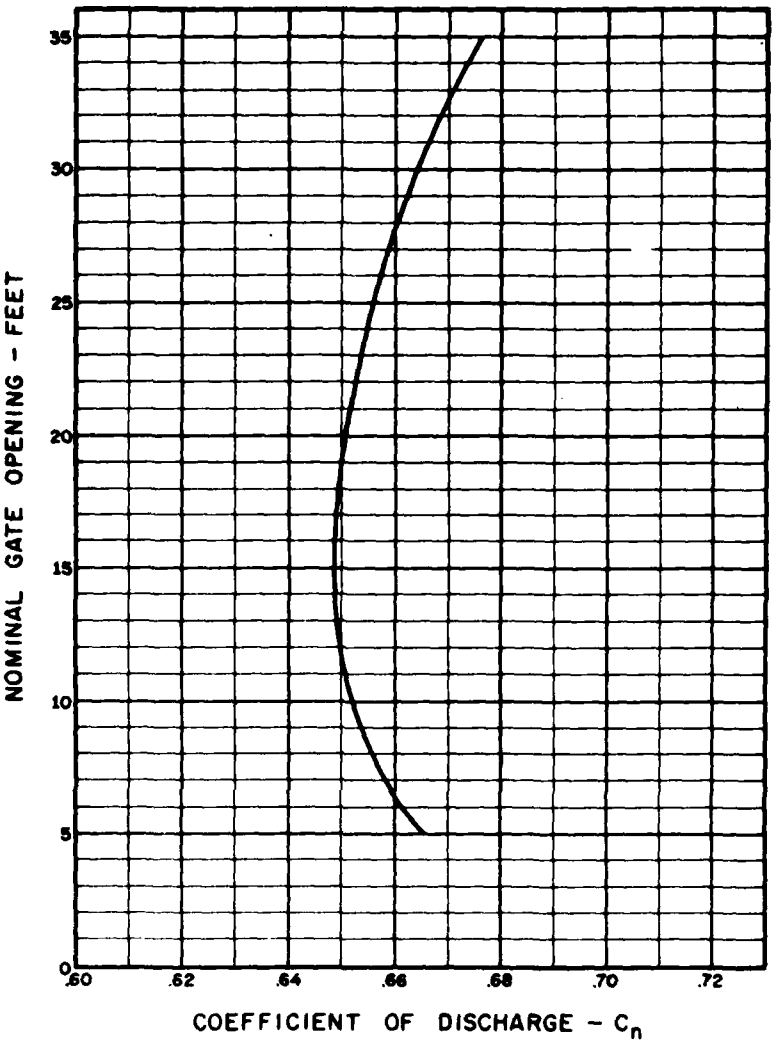

SPILLWAY RATING CURVES
DISCHARGE PER BAY IN 1000 CFS
TOTAL HEAD ON CREST IN FEET
FREE FLOW
ZONE OF UNCONTROLLABLE FLOW
LOWER LIMIT OF CONTROLLABLE GATED FLOW
POOL ELEVATION 738
CREST ELEV 681.0
NOMINAL GATE OPENINGS
3 FT
5 FT
7 FT
10 FT
15 FT
20 FT
25 FT
30 FT
35 FT

PLATE 6



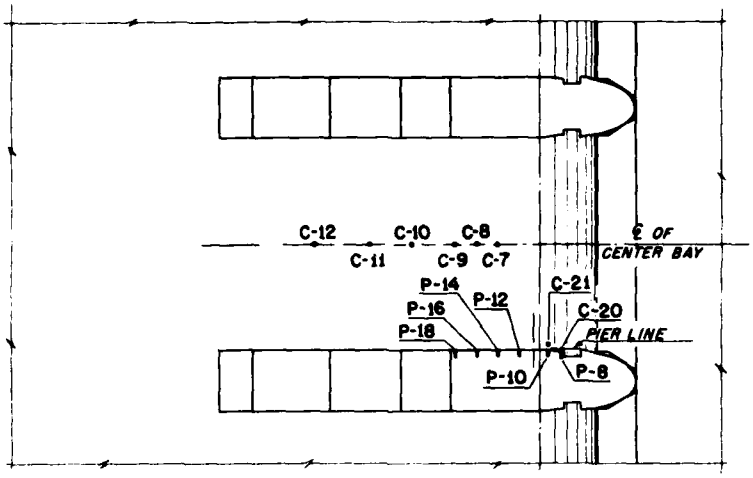
NOTES

1. UNIFORM MULTIPLE GATE OPERATION.
2. $C_n = \frac{Q_1}{A_1\sqrt{2gh}}$, COEFFICIENT OF DISCHARGE FOR NOMINAL GATE OPENING

DISCHARGE COEFFICIENT CURVE

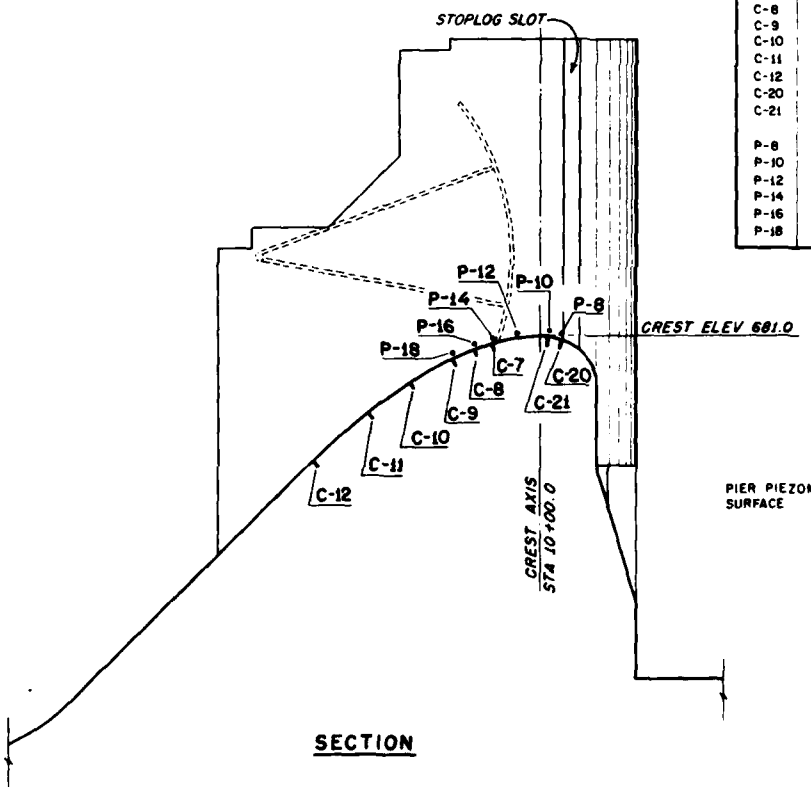
GATED FLOW
POOL ELEV 738

PLATE 7



PLAN

PIEZOMETER LOCATIONS		
PIEZ NO.	STATION	ELEVATION
C-7	10+10.0	679.7
C-8	10+15.0	678.2
C-9	10+20.0	676.3
C-10	10+30.0	670.9
C-11	10+40.0	663.9
C-12	10+53.1	652.1
C-20	9+95.2	680.5
C-21	9+98.4	680.9
P-8	9+95.2	681.5
P-10	9+98.4	681.9
P-12	10+05.0	681.6
P-14	10+10.0	680.7
P-16	10+15.0	679.2
P-18	10+20.0	677.3



SECTION

NOTE

PIER PIEZOMETERS 1.0 FT ABOVE CREST SURFACE

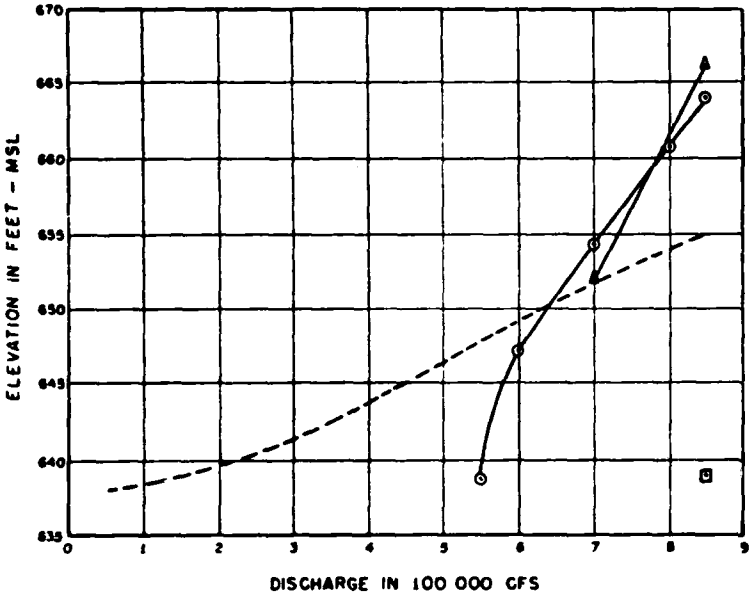
SCALE

0 25 50 FT

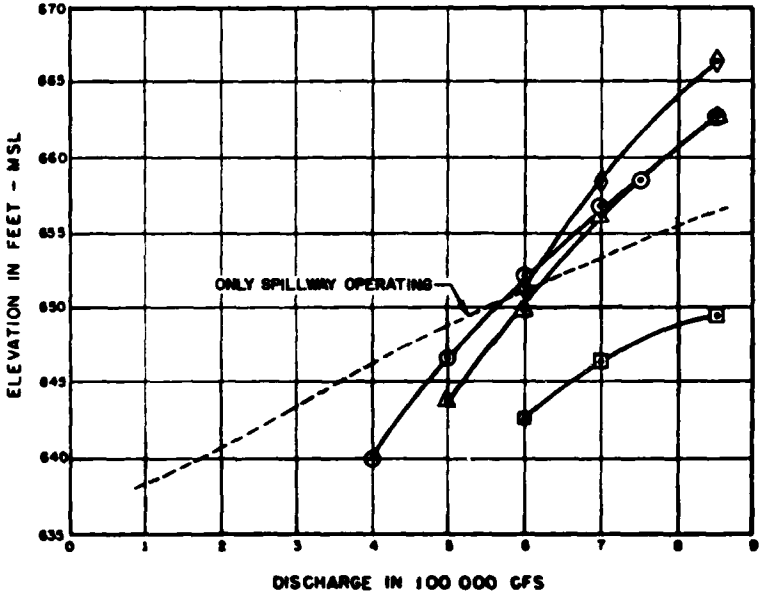
PIEZOMETER LOCATIONS

CREST AND PIERS

PLATE 8



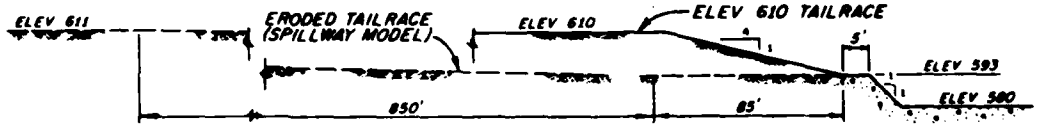
TAILRACE EXCAVATED TO ELEV 610



ERODED TAILRACE

LEGEND

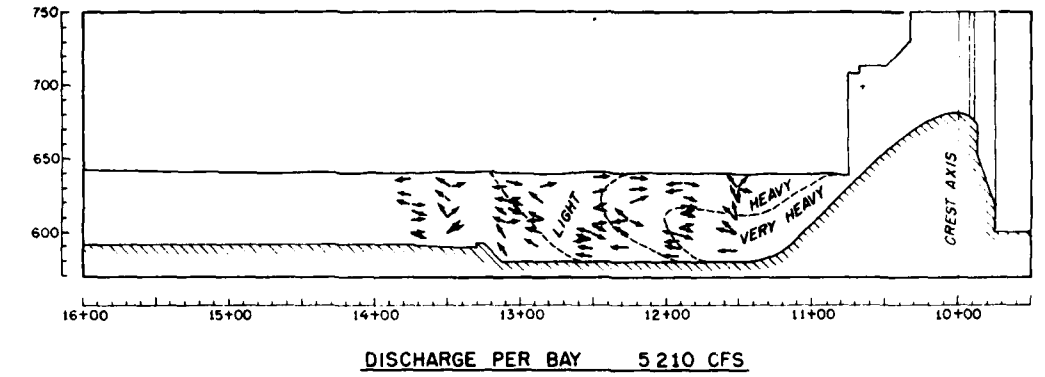
- NORMAL TAILWATER 1000 FT DOWNSTREAM FROM SPILLWAY AXIS.
- ⊙ MINIMUM TAILWATER REQUIRED TO HOLD A HYDRAULIC JUMP AT P.T. OF STILLING BASIN IN 3-BAY SPILLWAY MODEL.
- △ MINIMUM TAILWATER REQUIRED TO HOLD A HYDRAULIC JUMP AT P.T. OF STILLING BASIN IN 3-BAY FLUME IN GENERAL MODEL.
- ⊡ MINIMUM TAILWATER REQUIRED TO HOLD A HYDRAULIC JUMP AT P.T. OF STILLING BASIN IN 8-BAY GENERAL MODEL.
- ◇ MINIMUM TAILWATER REQUIRED TO HOLD A HYDRAULIC JUMP AT P.T. OF STILLING BASIN IN 8-BAY GENERAL MODEL WITH RETURN FLOW CUT OFF.



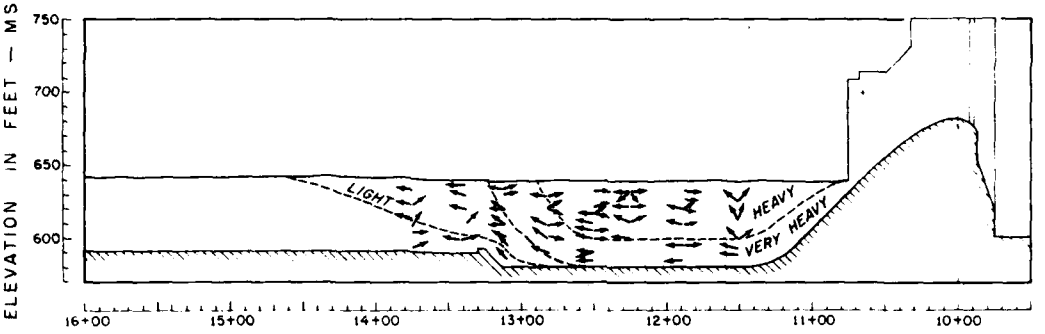
MINIMUM TAILWATER CURVES

PLAN A STILLING BASIN

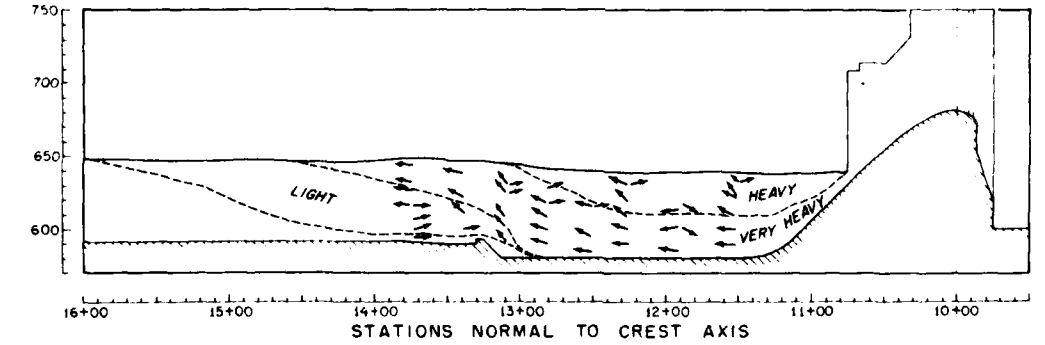
PLATE 9



DISCHARGE PER BAY 5 210 CFS



DISCHARGE PER BAY 10 150 CFS



DISCHARGE PER BAY 15 100 CFS

LEGEND

--------- ZONES OF AERATION

AERATION AND FLOW DIRECTIONS IN STILLING BASIN

NO DEFLECTORS

PLATE 10

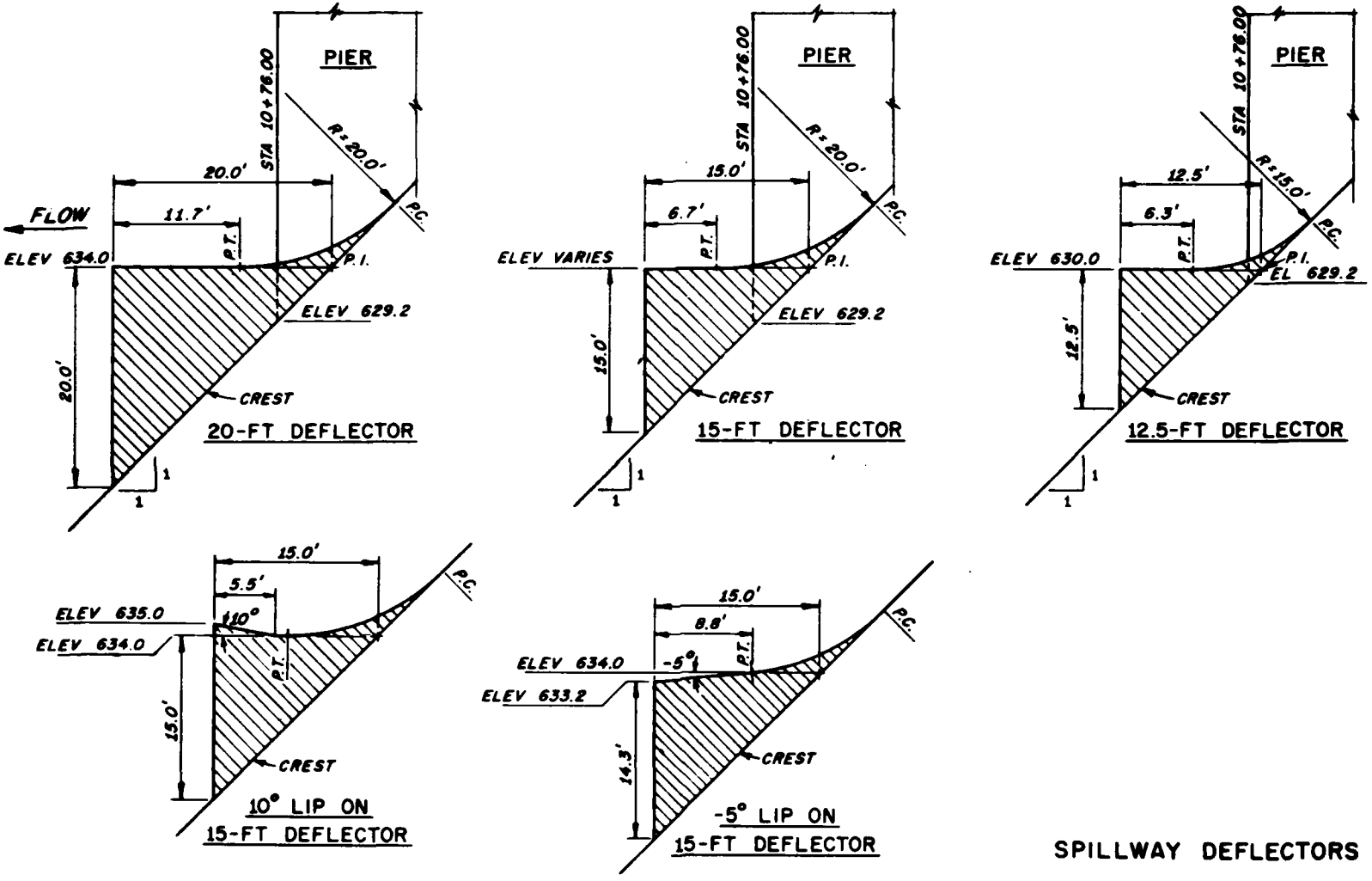
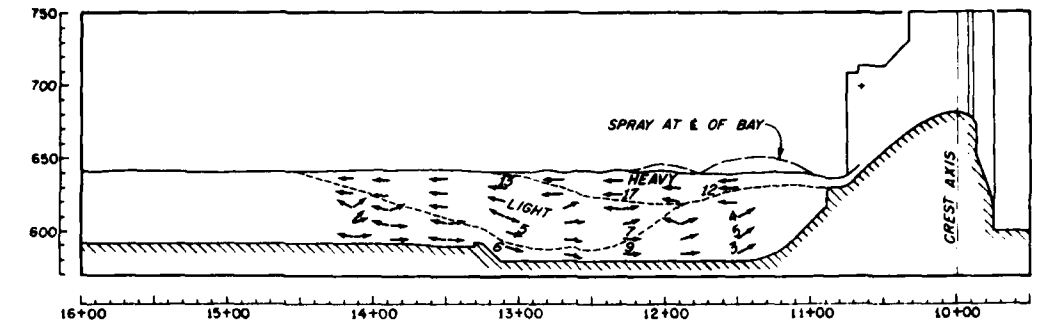
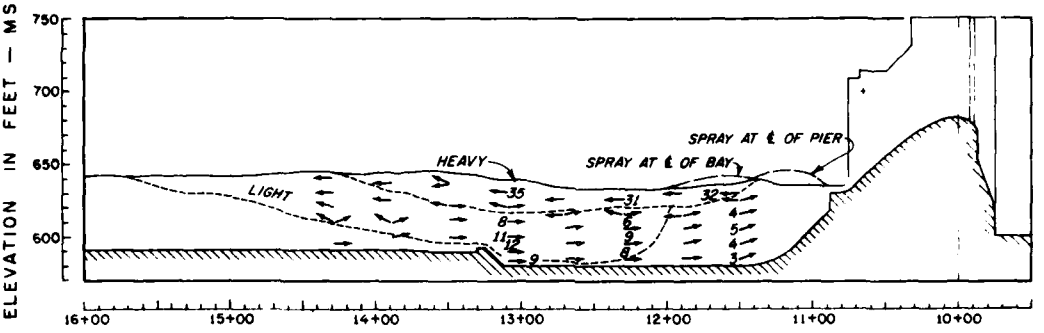

PIER
STA 10+76.00
R=20.0'
20.0'
FLOW
11.7'
P.T.
P.C.
P.I.
ELEV 634.0
ELEV 629.2
20.0'
CREST
1
1
20-FT DEFLECTOR
PIER
STA 10+76.00
R=20.0'
15.0'
6.7'
P.T.
P.C.
P.I.
ELEV VARIES
ELEV 629.2
15.0'
CREST
1
1
15-FT DEFLECTOR
PIER
STA 10+76.00
R=15.0'
12.5'
6.3'
P.T.
P.C.
P.I.
ELEV 630.0
EL 629.2
12.5'
CREST
1
1
12.5-FT DEFLECTOR
15.0'
5.5'
P.C.
ELEV 635.0
10°
ELEV 634.0
P.T.
15.0'
CREST
10° LIP ON
15-FT DEFLECTOR
15.0'
8.8'
P.C.
ELEV 634.0
-5°
P.T.
ELEV 633.2
14.3'
CREST
-5° LIP ON
15-FT DEFLECTOR
SPILLWAY DEFLECTORS

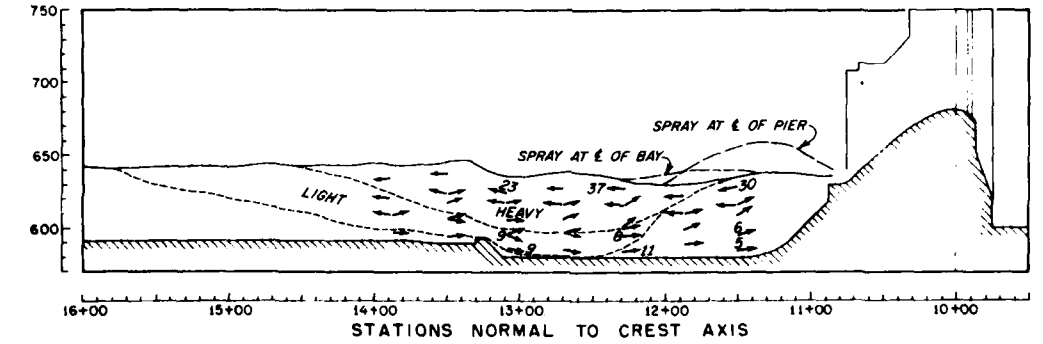
PLATE 11



DISCHARGE PER BAY 5210 CFS



DISCHARGE PER BAY 10150 CFS



DISCHARGE PER BAY 15100 CFS

LEGEND

---------- ZONES OF AERATION

5 VELOCITY IN FPS

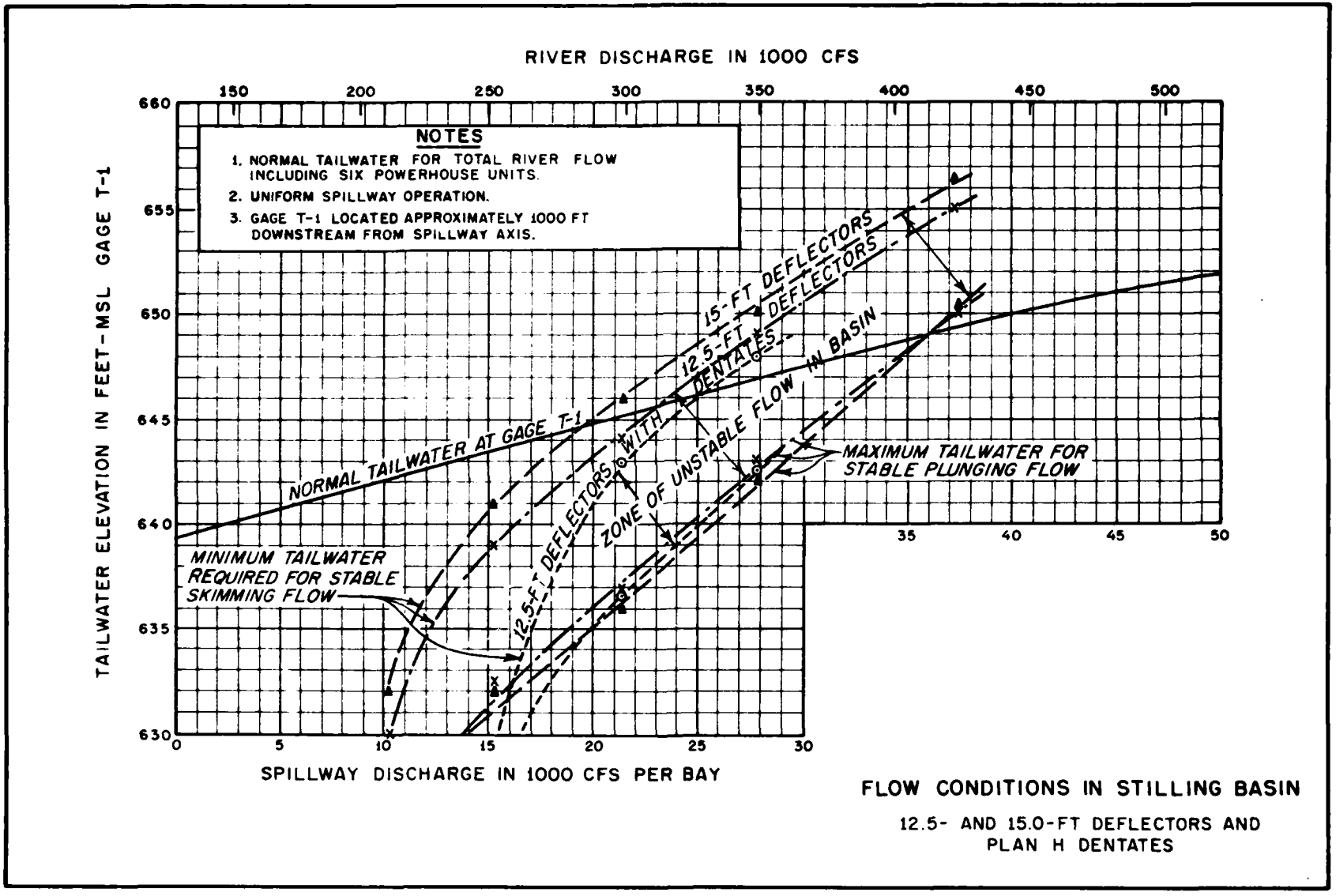
NOTE

DETAILS OF DEFLECTORS SHOWN ON PLATE 11

FLOW CONDITIONS IN STILLING BASIN

12.5-FT DEFLECTOR AT ELEV 630

PLATE 12

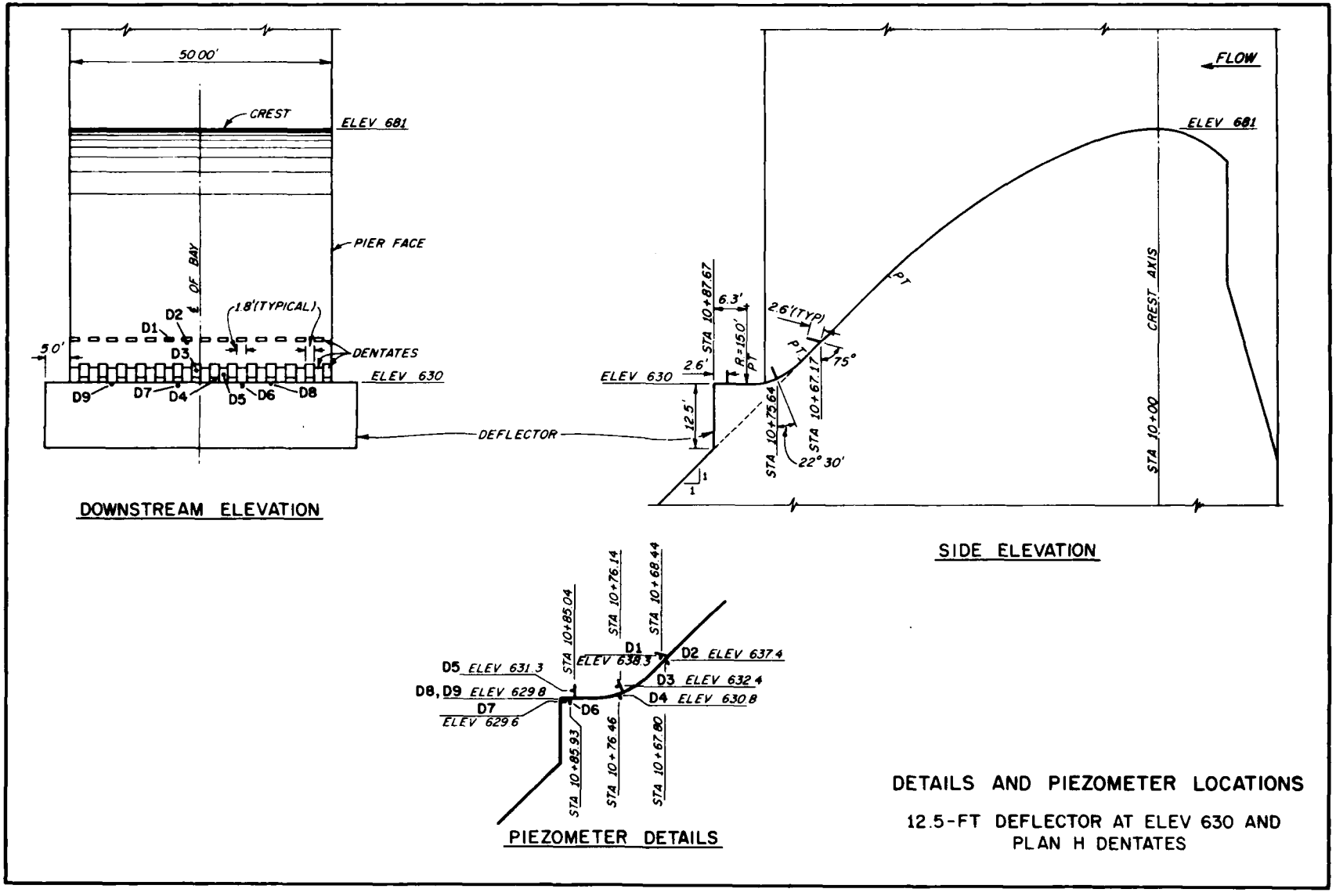


FLOW CONDITIONS IN STILLING BASIN

12.5- AND 15.0-FT DEFLECTORS AND PLAN H DENTATES

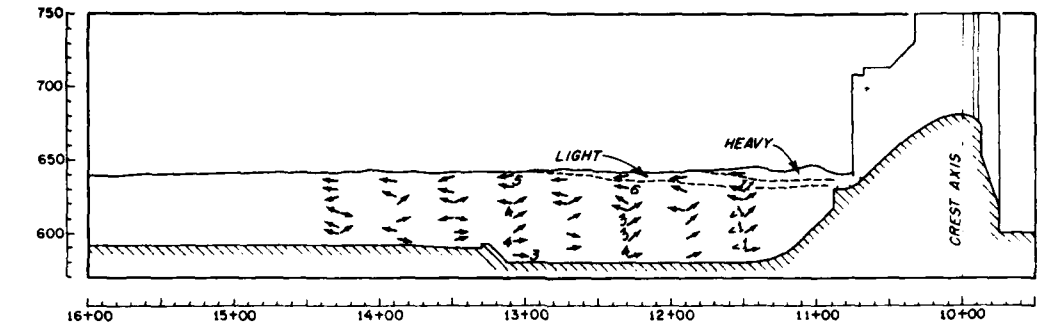
PLATE 13

PLATE 14

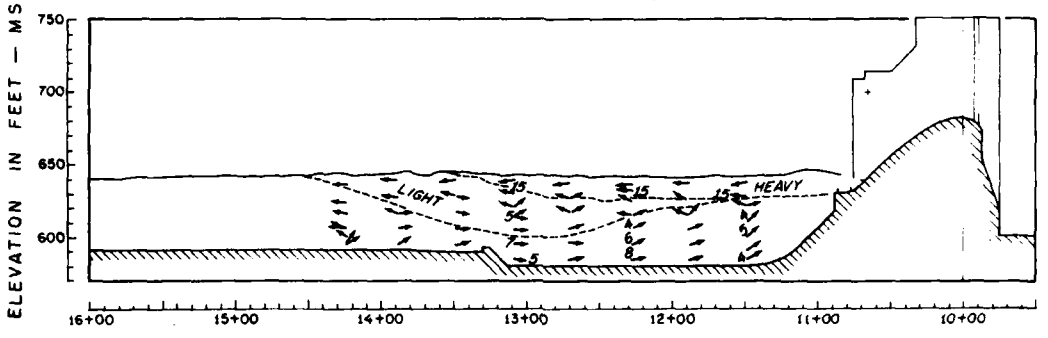


DETAILS AND PIEZOMETER LOCATIONS

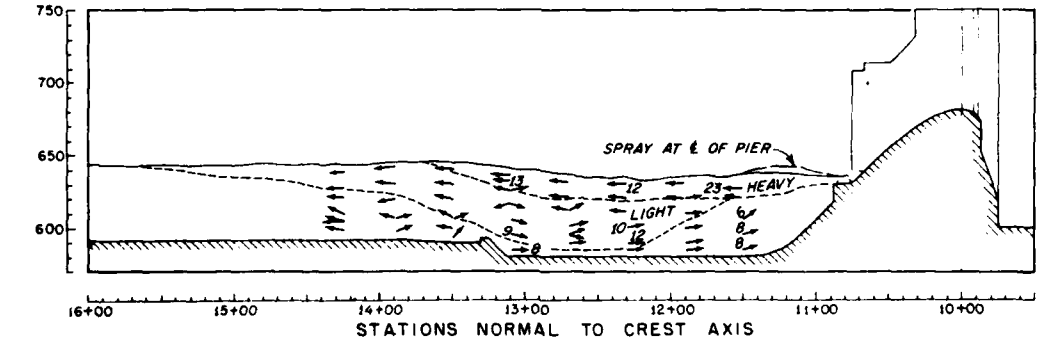
12.5-FT DEFLECTOR AT ELEV 630 AND PLAN H DENTATES



DISCHARGE PER BAY 5210 CFS



DISCHARGE PER BAY 10150 CFS



DISCHARGE PER BAY 15100 CFS

LEGEND

---------- ZONES OF AERATION

5 VELOCITY IN FPS

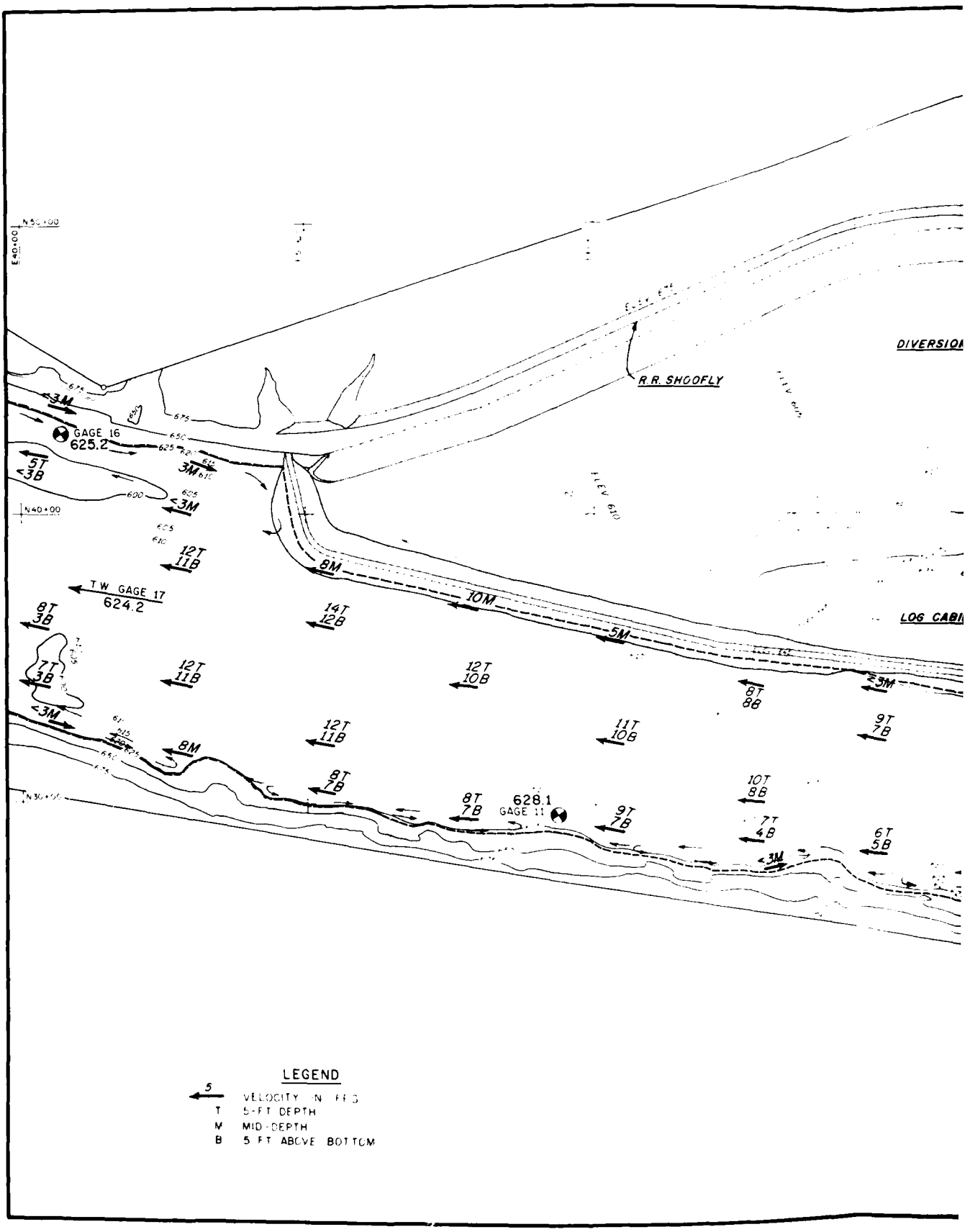
NOTES

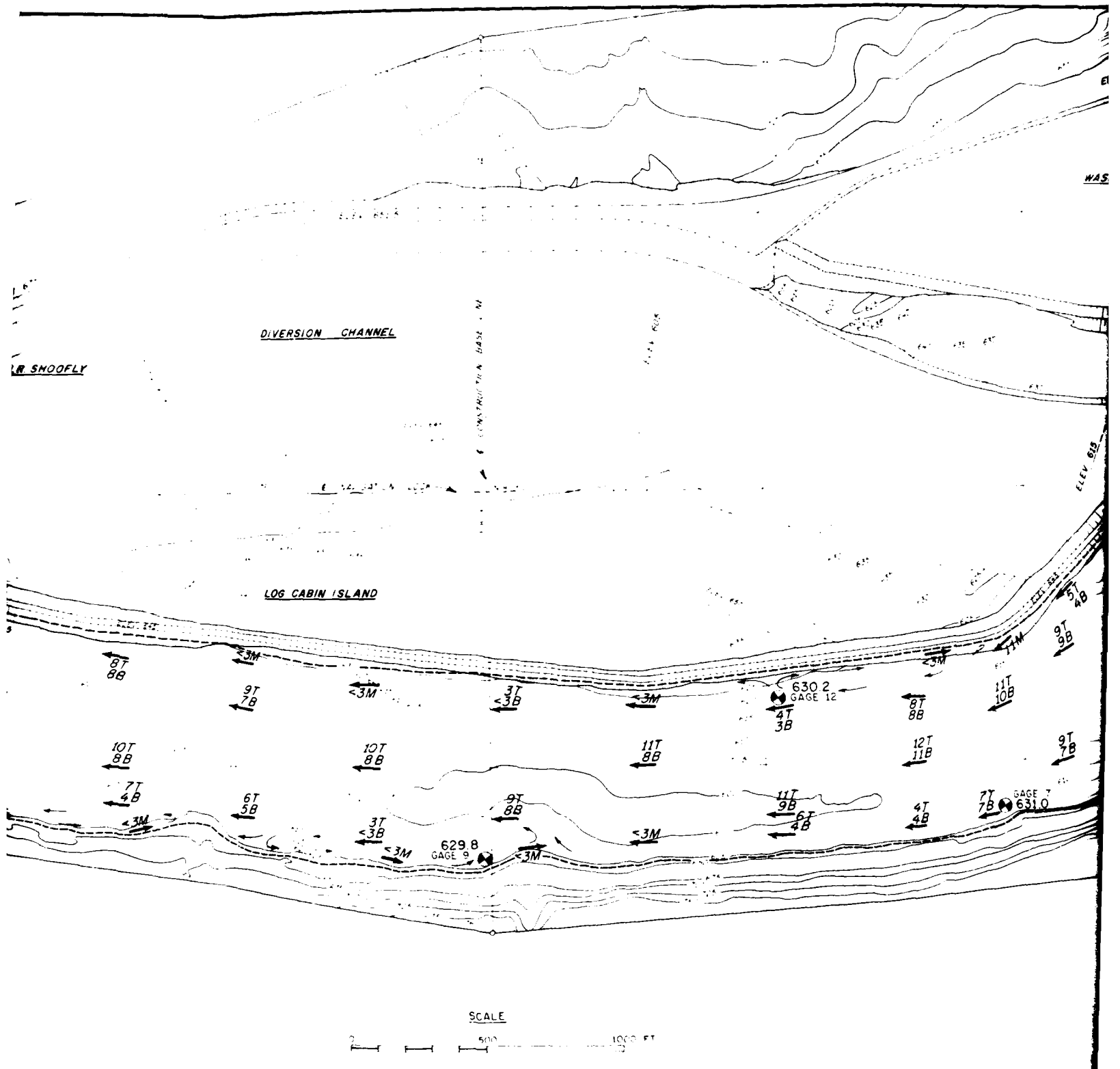
1. DETAILS OF DEFLECTORS SHOWN ON PLATE 11
2. DETAILS OF DENTATE PLAN H SHOWN ON PLATE 14

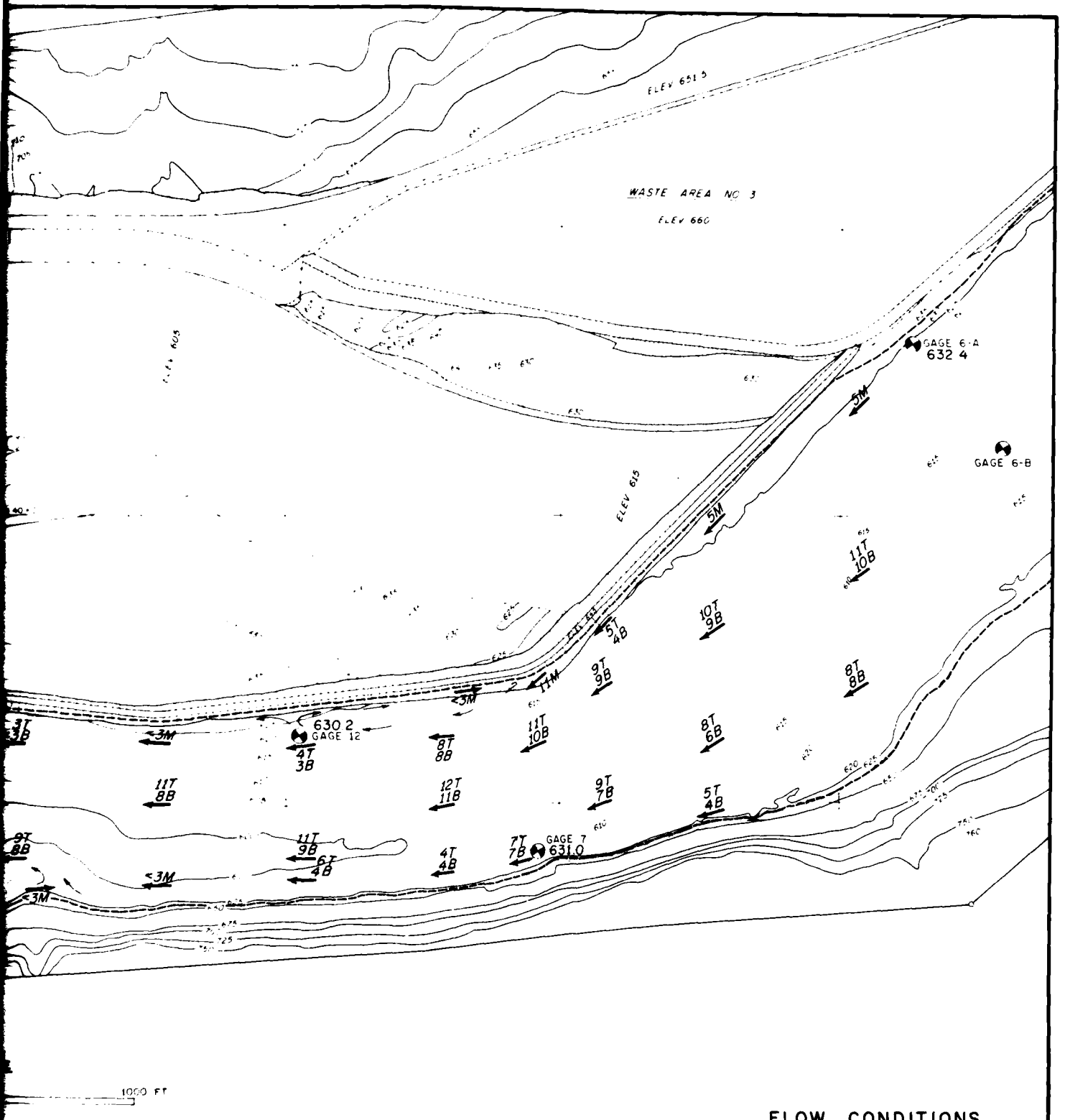
FLOW CONDITIONS IN STILLING BASIN

12.5-FT DEFLECTOR AT ELEV 630
PLAN H DENTATES

PLATE 15


N50+00
E40+00
N40+00
N30+00
DIVERSION
R.R. SHOOFLY
ELEV 610
GAGE 16
625.2
TW GAGE 17
624.2
GAGE 11
628.1
LOG CABI
3M
5T
3B
3M
12T
11B
8M
10M
5M
8T
3B
14T
12B
7T
3B
12T
11B
12T
10B
8T
8B
3M
9T
7B
11T
10B
8M
12T
11B
8T
7B
8T
7B
9T
7B
10T
8B
7T
4B
3M
6T
5B
LEGEND
5 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM


DIVERSION CHANNEL
R SHOOFLY
LOG CABIN ISLAND
ELEV 615
630.2
GAGE 12
629.8
GAGE 9
631.0
GAGE 7
SCALE
500
1000 FT

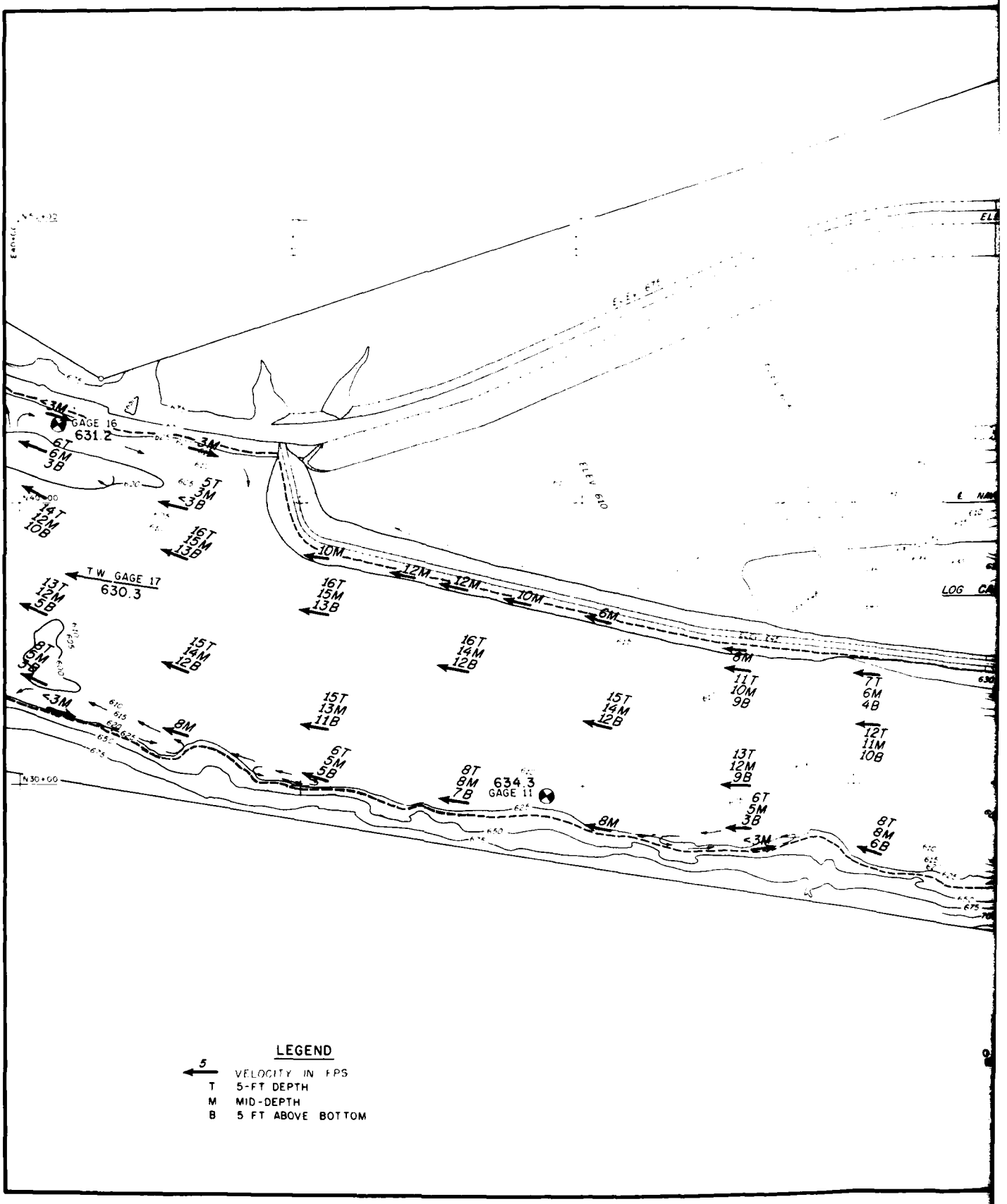


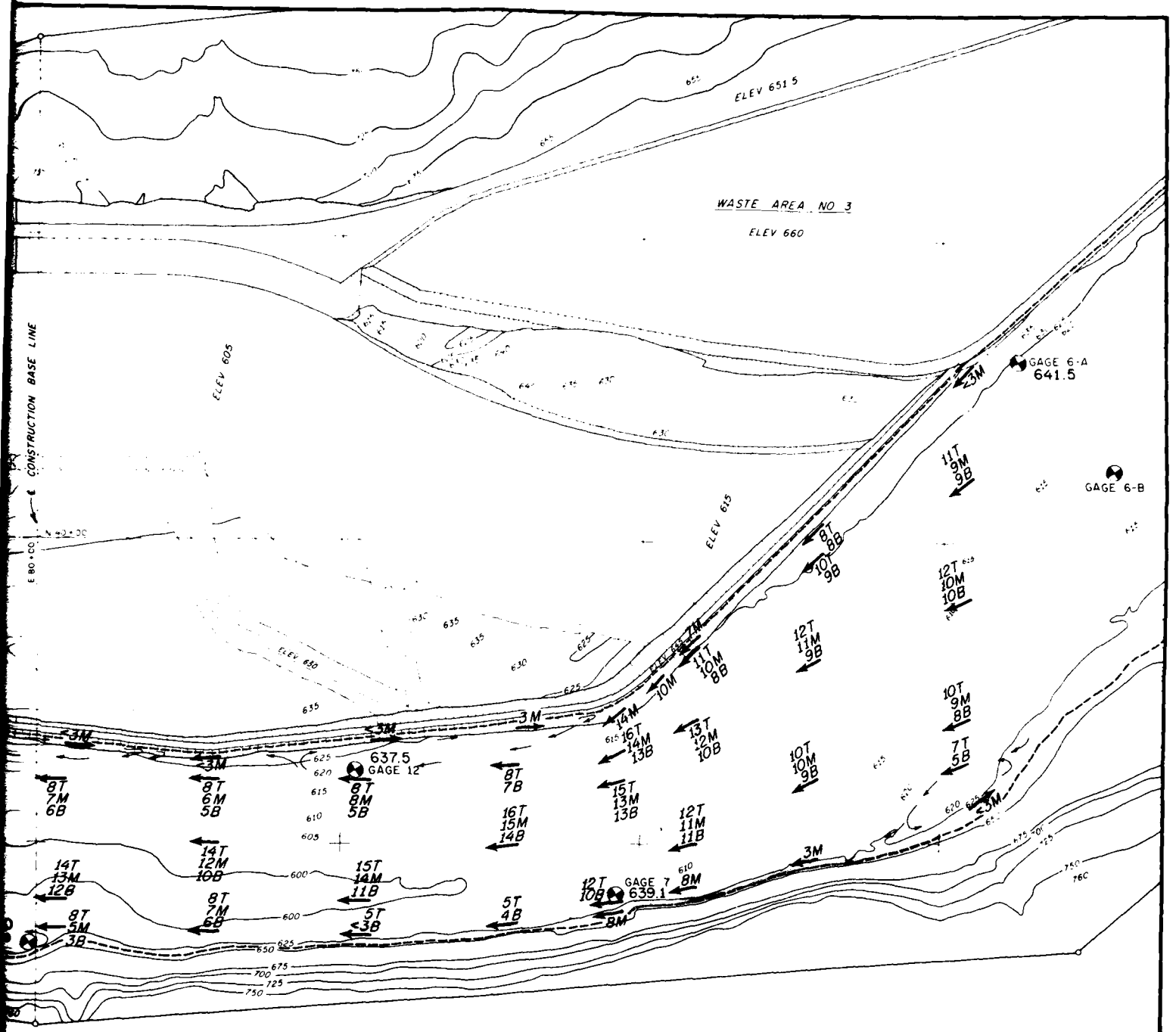
FLOW CONDITIONS

PLAN A CONTRACTORS DIKE
FIRST-STEP COFFERDAM

RIVER DISCHARGE 100000 CFS

PLATE 16


GAGE 16
631.2
TW GAGE 17
630.3
GAGE 11
634.3
LOG CA
N40+00
N30+00
LEGEND
5 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM

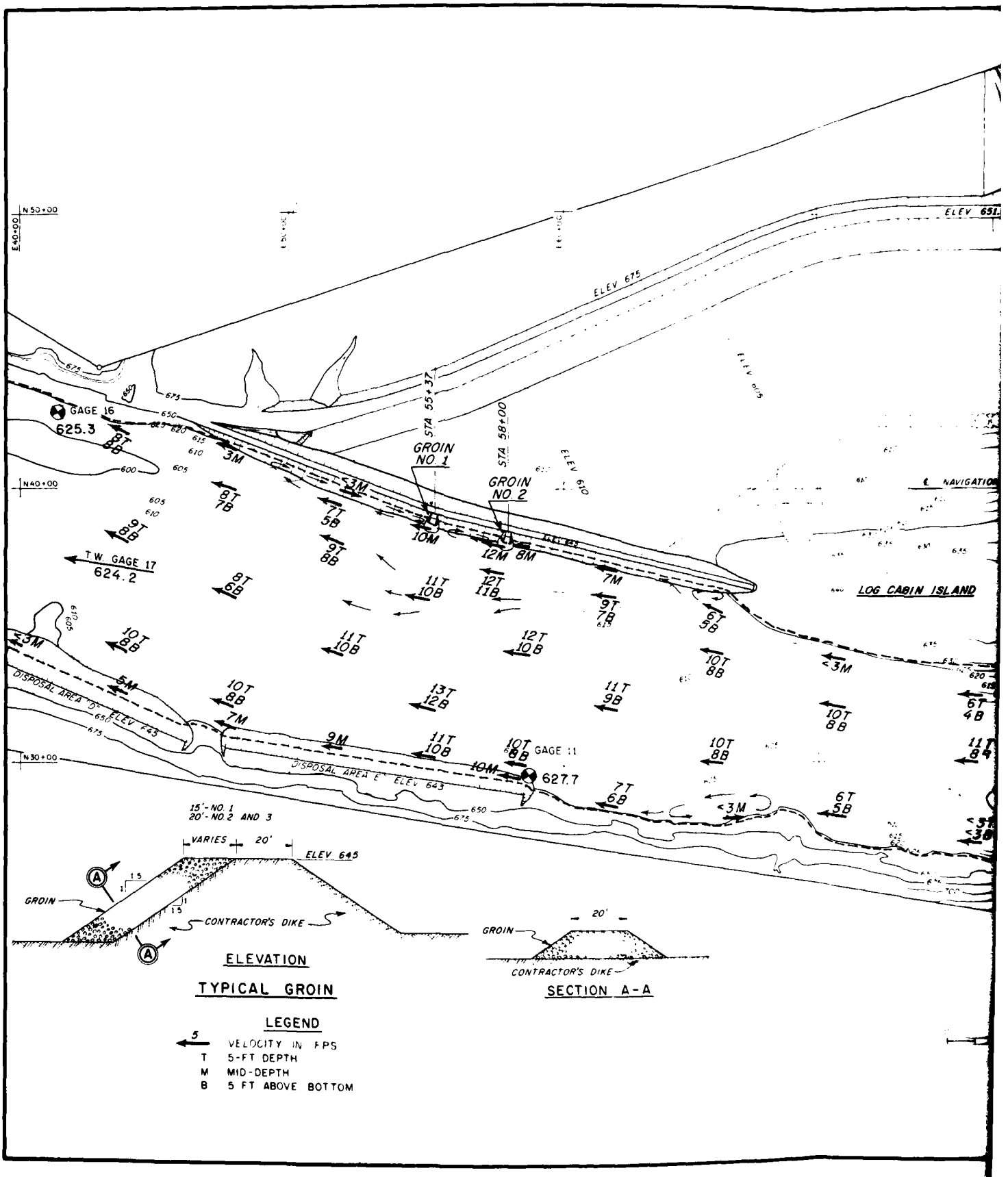


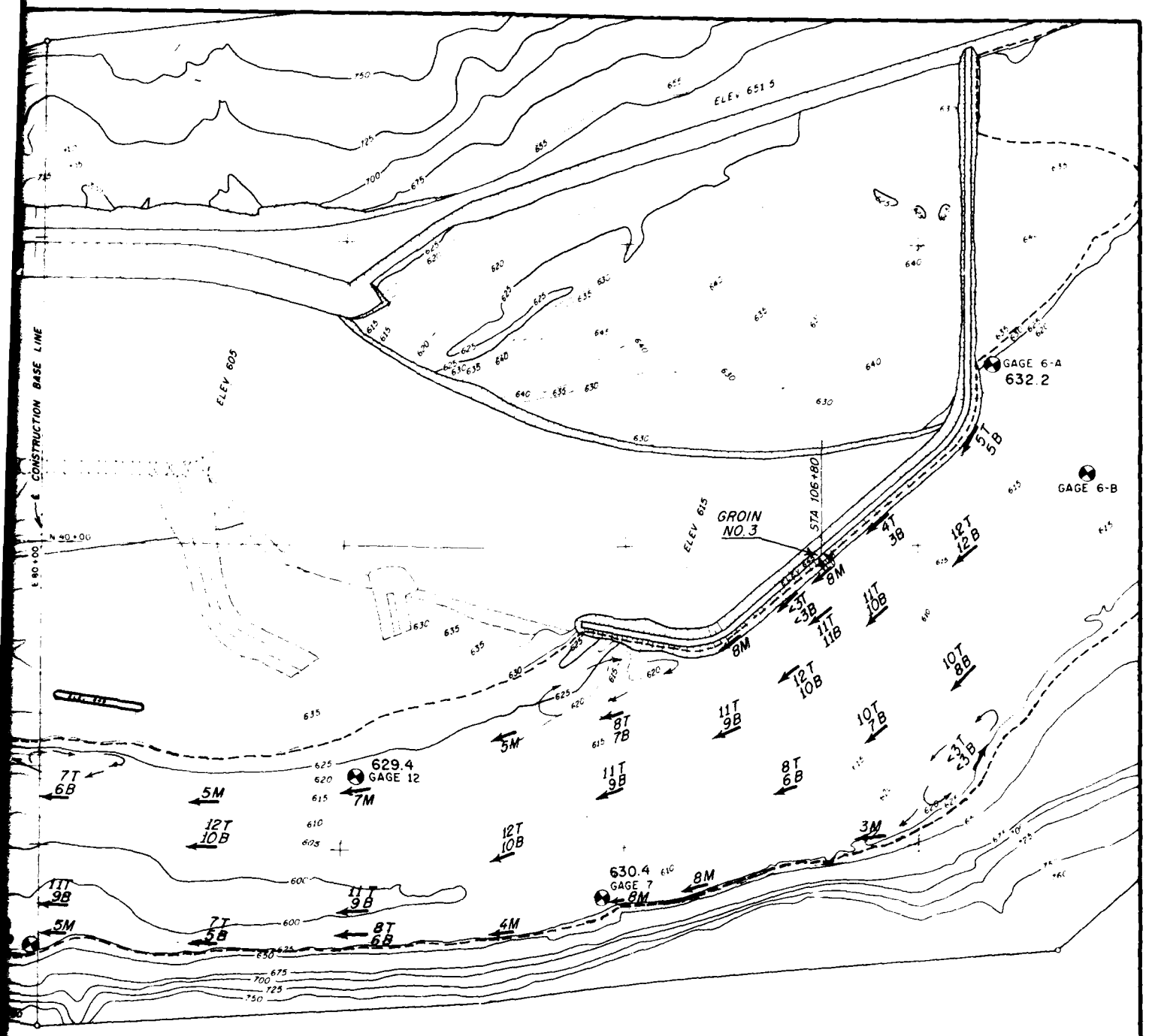
FLOW CONDITIONS

PLAN A CONTRACTORS DIKE
FIRST-STEP COFFERDAM

RIVER DISCHARGE 200000 CFS

PLATE 17


N 50+00
E 40+00
N 40+00
N 30+00
ELEV 675
ELEV 651
GAGE 16
625.3
GROIN NO. 1
GROIN NO. 2
STA 55+37
STA 58+00
T.W. GAGE 17
624.2
LOG CABIN ISLAND
DISPOSAL AREA 'D' ELEV 643
DISPOSAL AREA 'E' ELEV 643
GAGE 11
627.7
15'- NO. 1
20'- NO. 2 AND 3
VARIES
20'
ELEV 645
GROIN
CONTRACTOR'S DIKE
ELEVATION
TYPICAL GROIN
SECTION A-A
LEGEND
5 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM

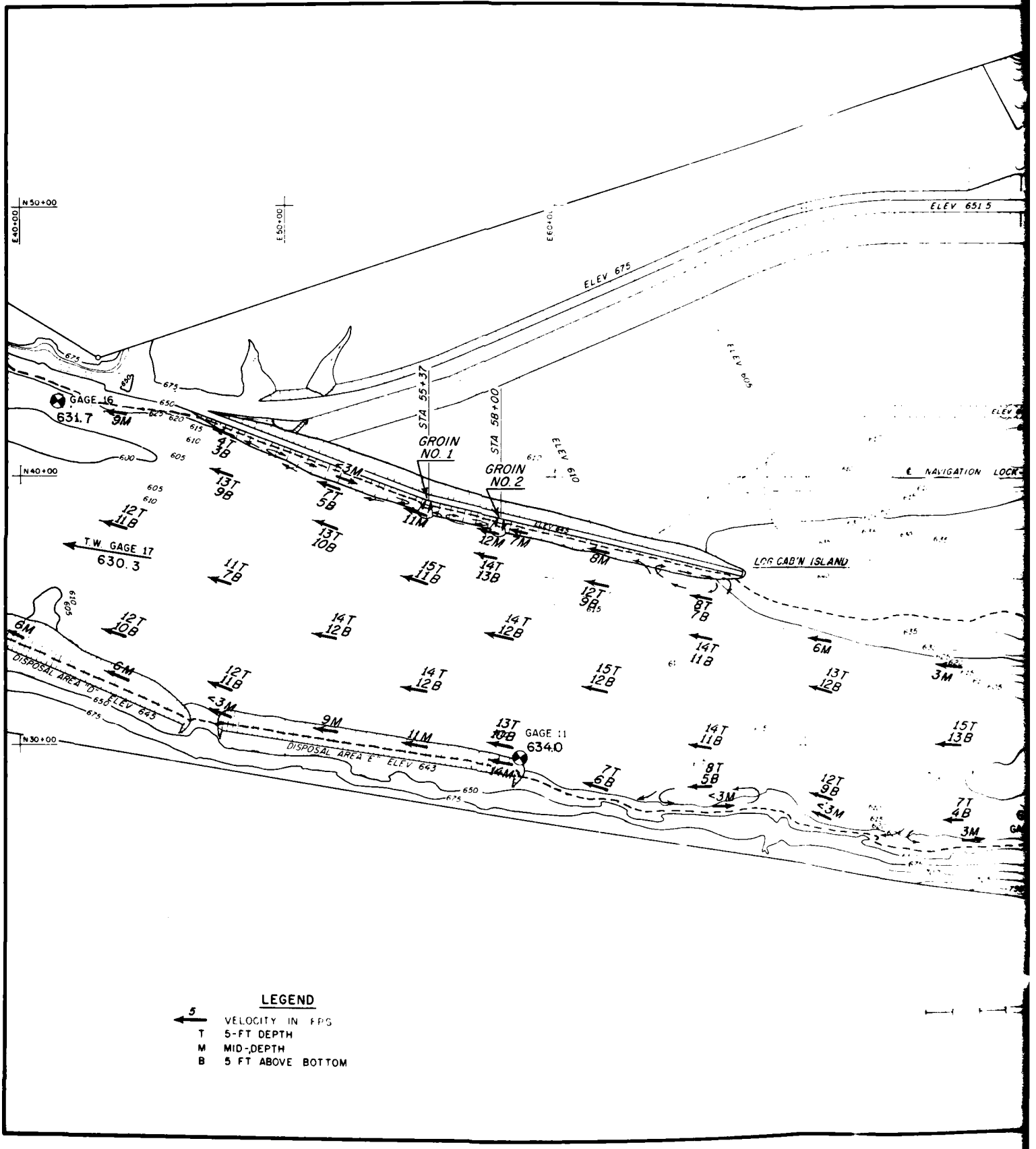


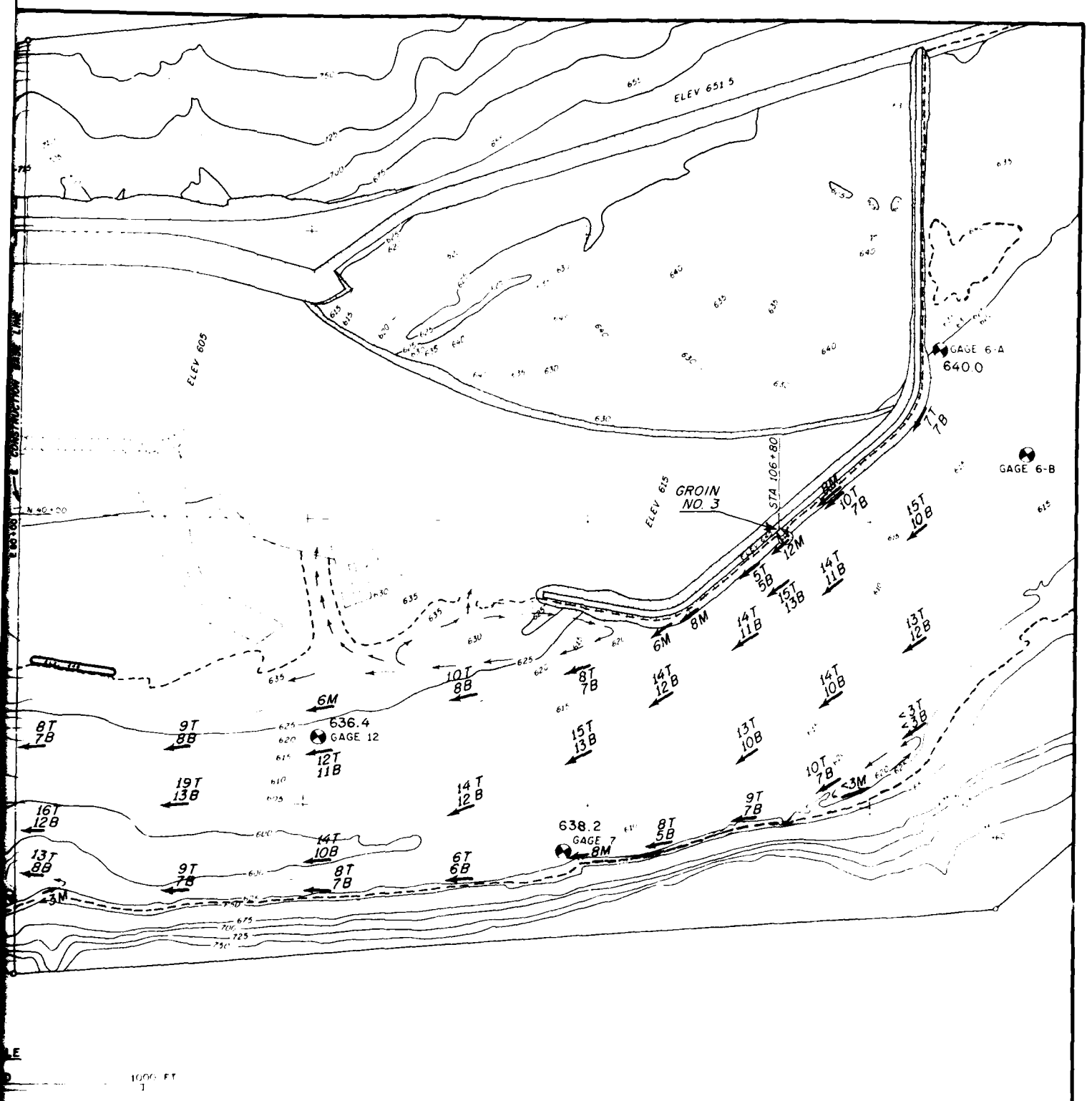
FLOW CONDITIONS

PLAN C CONTRACTORS DIKE WITH GROINS
FIRST-STEP COFFERDAM

RIVER DISCHARGE 100000 CFS

PLATE 18


N50+00
E40+00
E50+00
ELEV 651.5
ELEV 675
GAGE 16
631.7
STA 55+37
STA 58+00
GROIN NO. 1
GROIN NO. 2
N40+00
℄ NAVIGATION LOCK
T.W. GAGE 17
630.3
LOG CAB'N ISLAND
DISPOSAL AREA "D" ELEV 643
N30+00
DISPOSAL AREA "E" ELEV 643
GAGE 11
634.0
LEGEND
5 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM

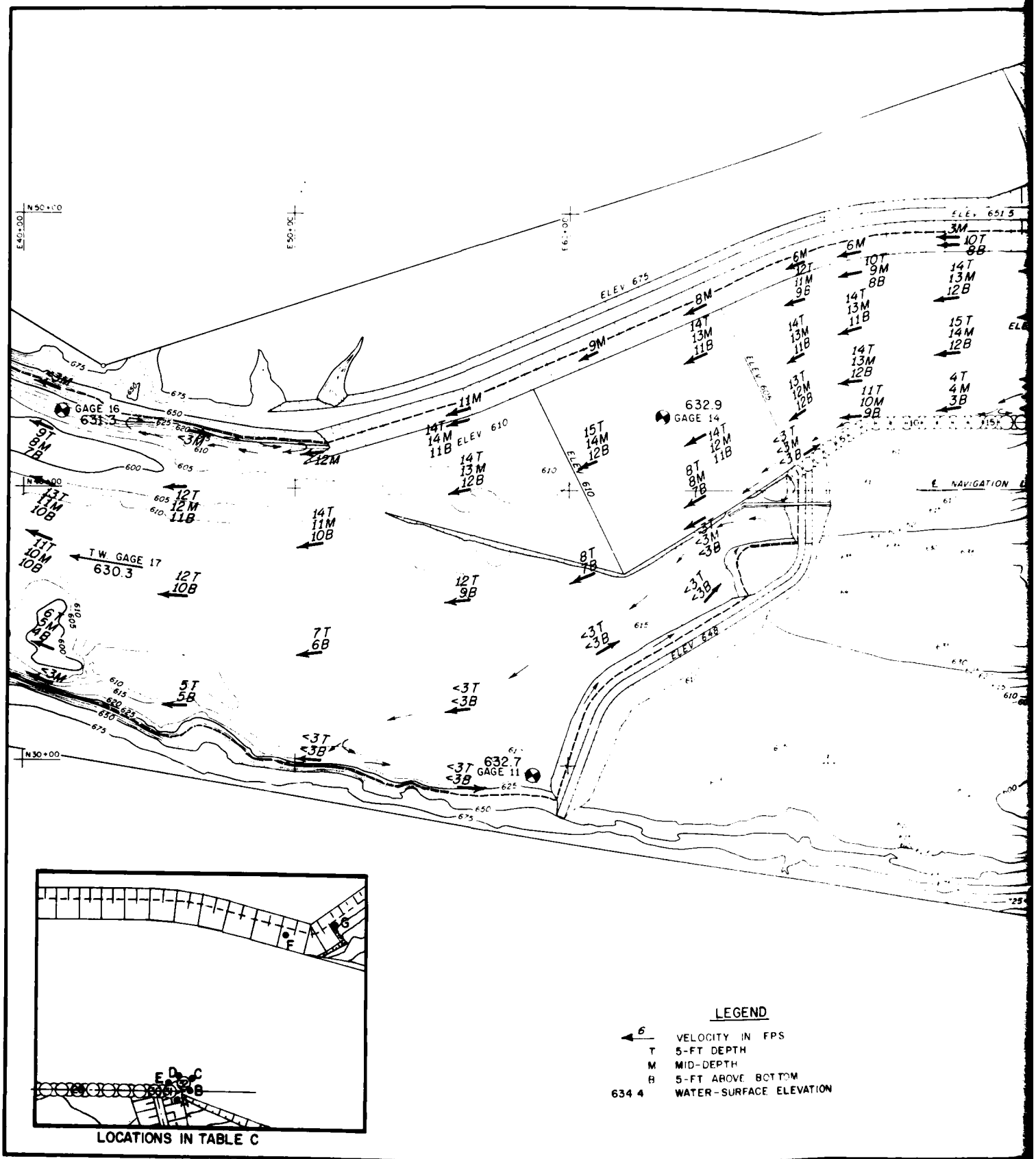


FLOW CONDITIONS

PLAN C CONTRACTORS DIKE WITH GROINS
FIRST-STEP COFFERDAM

RIVER DISCHARGE 200000 CFS

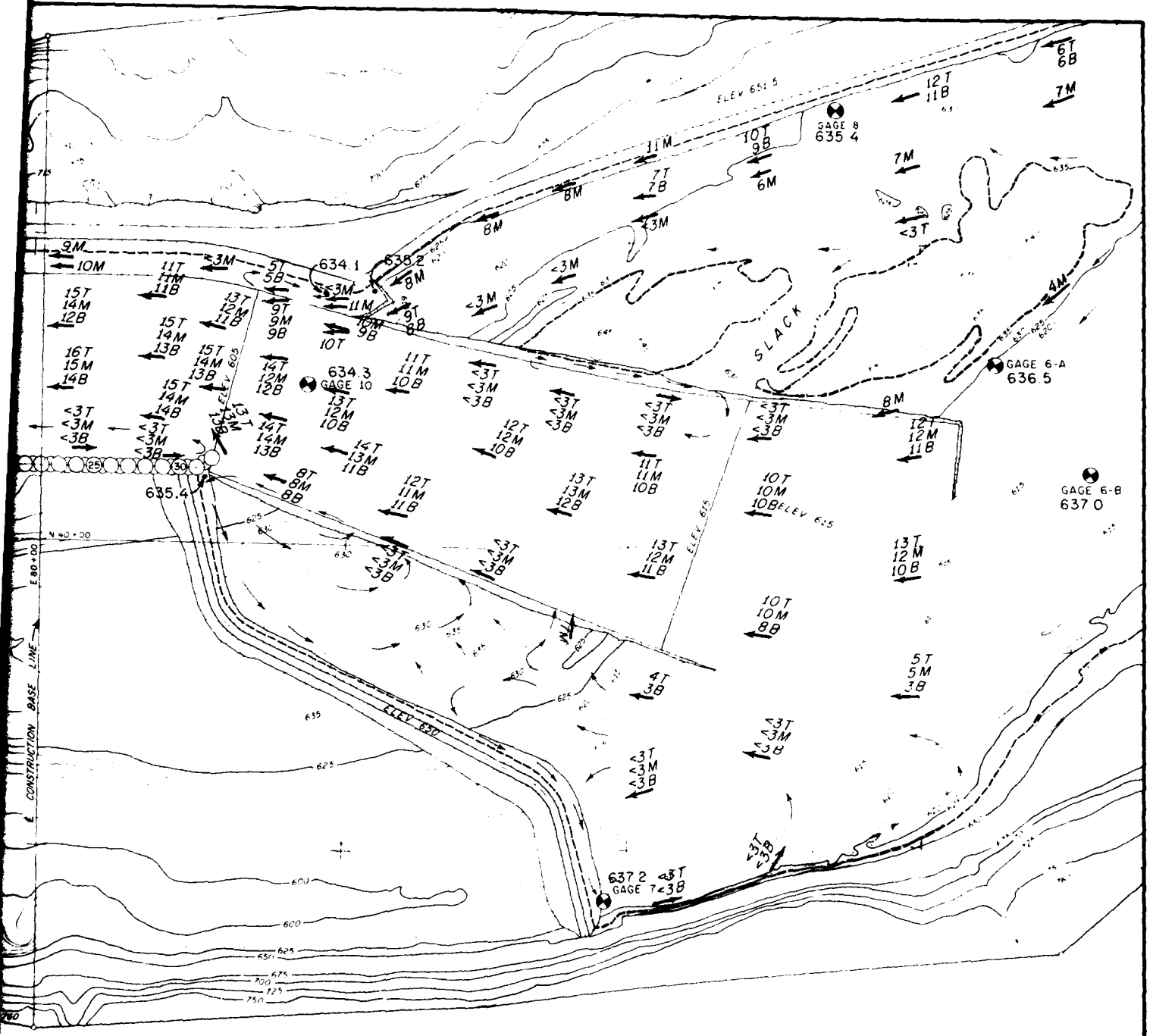
PLATE 19



LOCATIONS IN TABLE C

LEGEND

◀6	VELOCITY IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5-FT ABOVE BOTTOM
634.4	WATER-SURFACE ELEVATION



SCALE

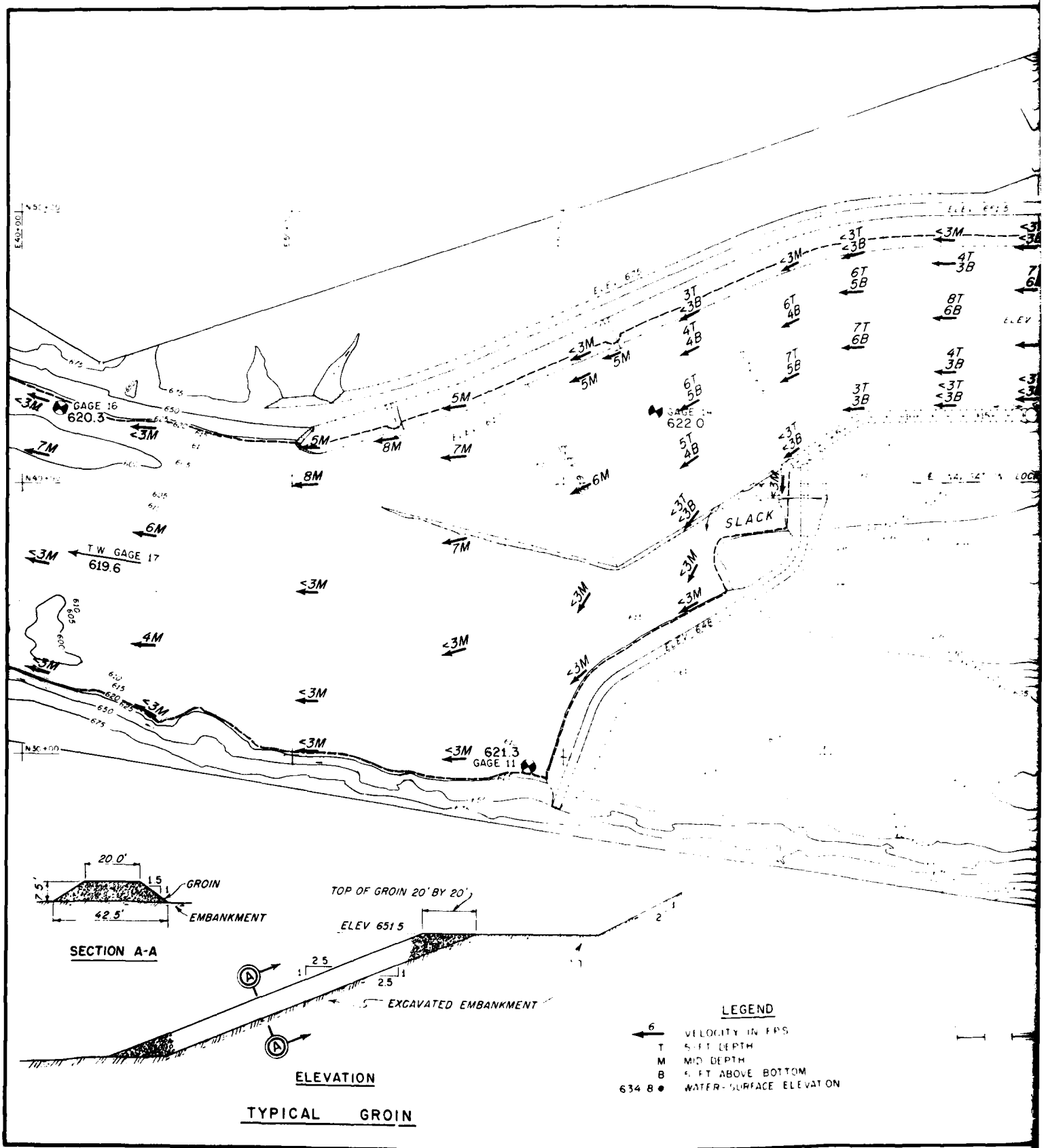
0 500 1000 FT

FLOW CONDITIONS

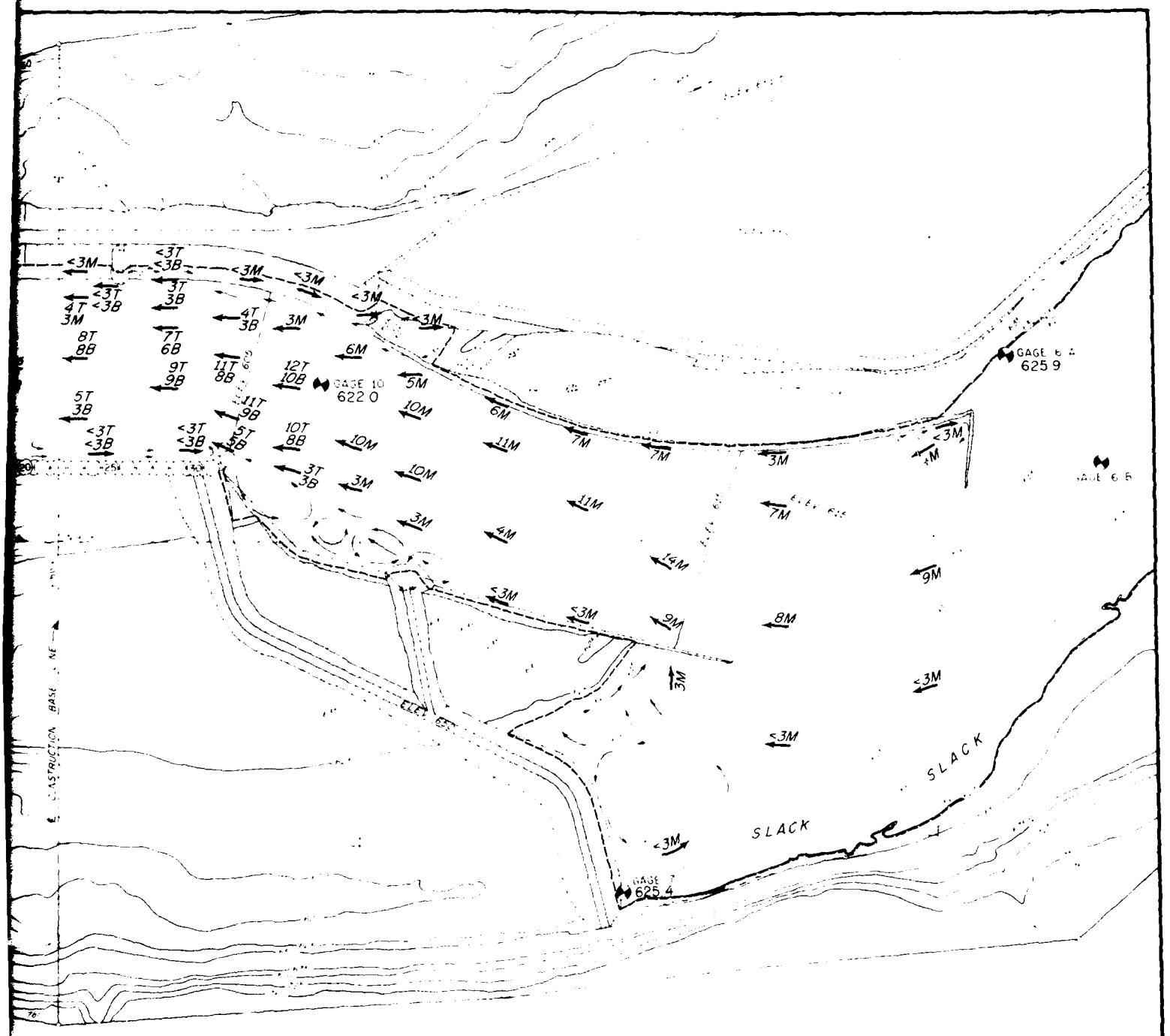
NATURAL TAILWATER
FIRST-STEP COFFERDAM

RIVER DISCHARGE 200000 CFS

PLATE 20



TYPICAL GROIN

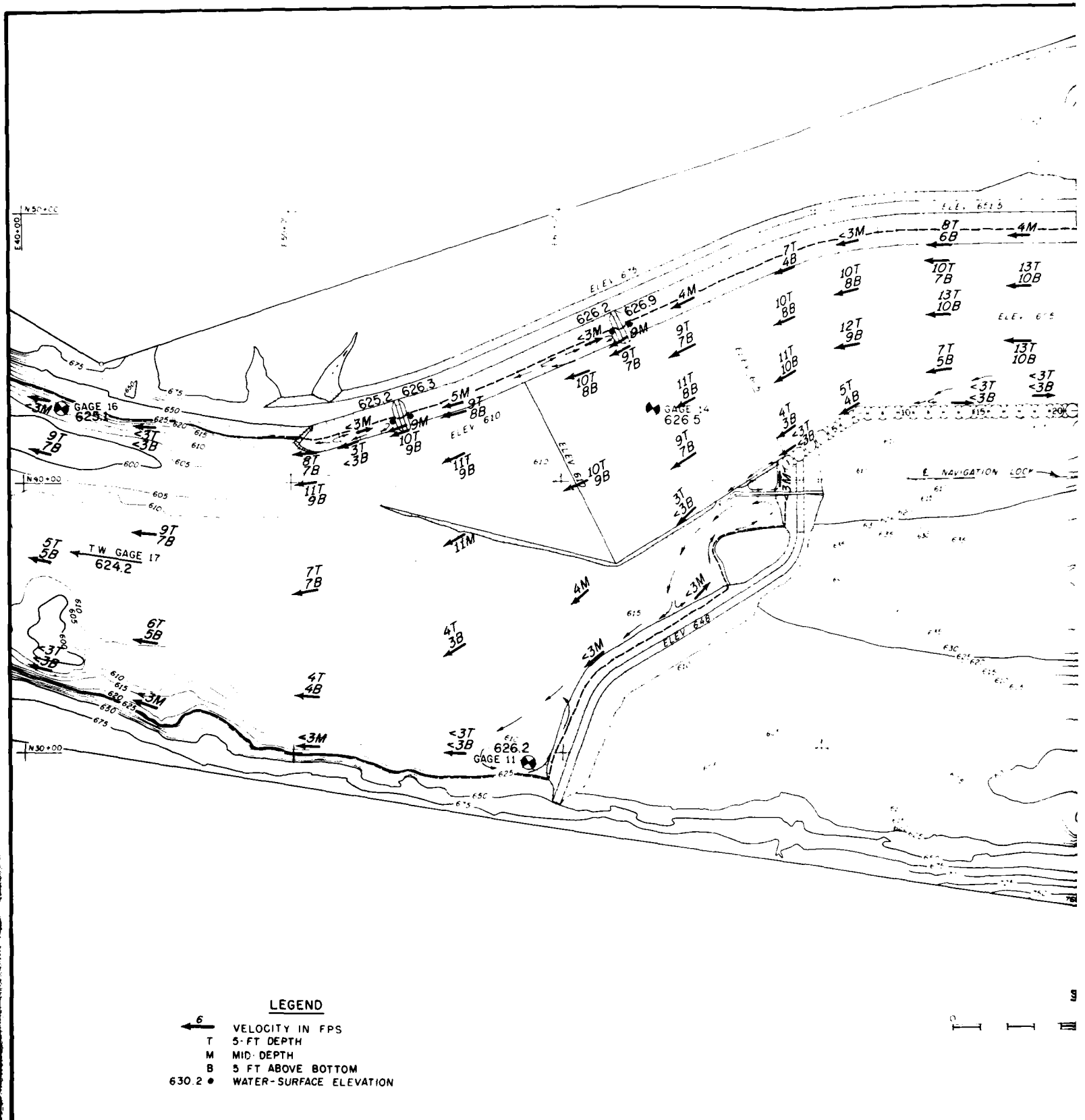


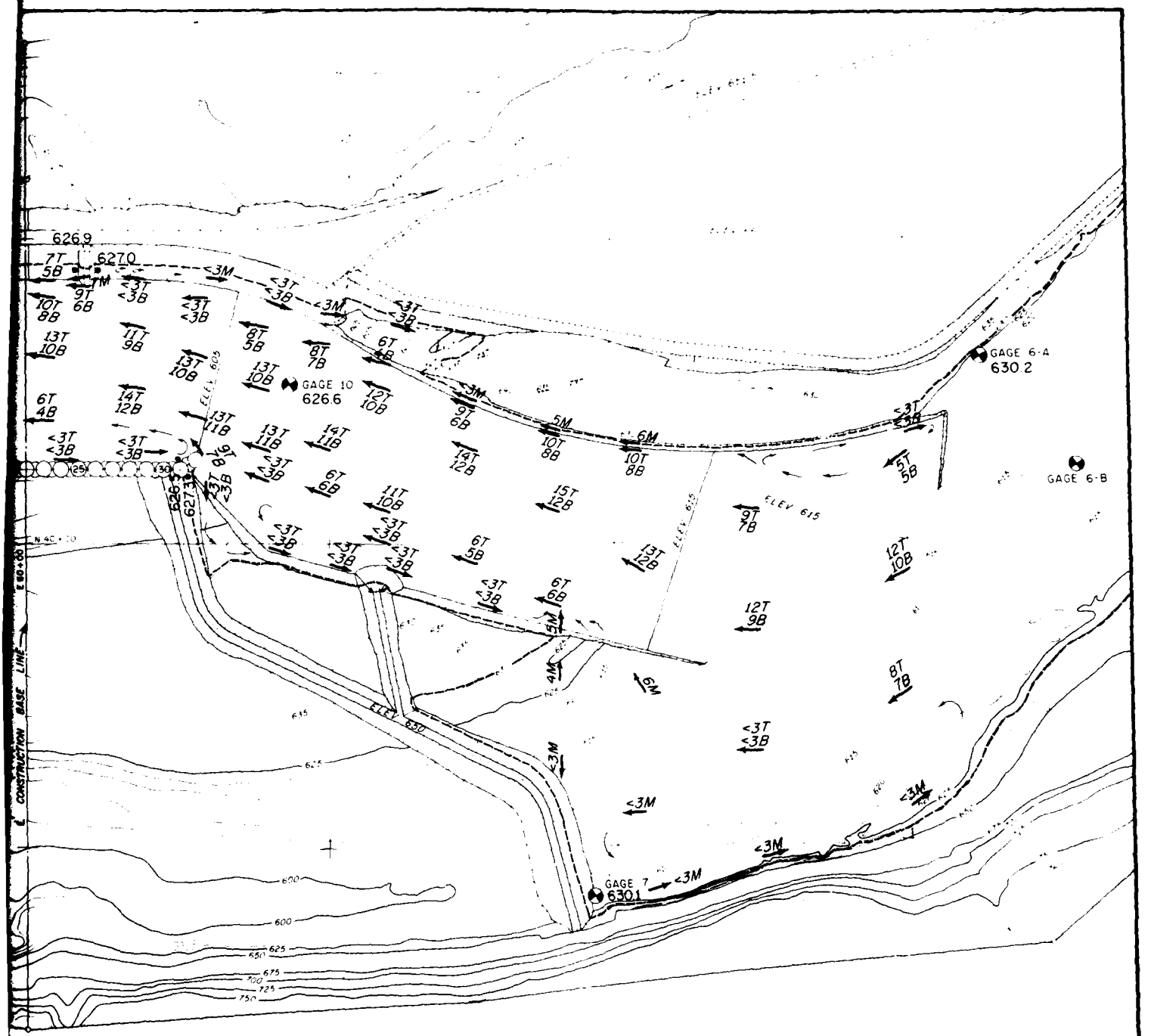
FLOW CONDITIONS

PLAN C DIVERSION CHANNEL ENTRANCE
FIRST-STEP COFFERDAM

RIVER DISCHARGE 50000 CFS

PLATE 21


N30+00
N40+00
N50+00
E NAVIGATION LOCK
ELEV 648
GAGE 16
625.1
TW GAGE 17
624.2
GAGE 14
626.5
GAGE 11
626.2
625.2
626.3
626.2
626.9
LEGEND
6 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
630.2 ● WATER-SURFACE ELEVATION



SCALE

500 1000 FT

FLOW CONDITIONS

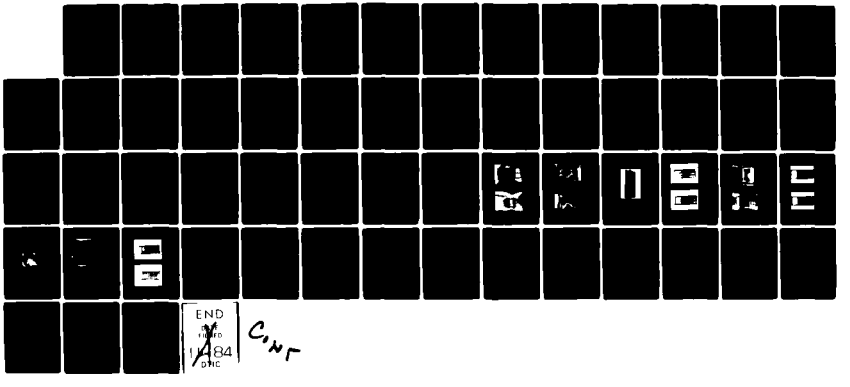
PLAN C DIVERSION CHANNEL ENTRANCE
FIRST-STEP COFFERDAM

RIVER DISCHARGE 10[illegible] CFS

PLATE 22

AD-A146 499 LOWER GRANITE DAM SNAKE RIVER WASHINGTON; HYDRAULIC MODEL INVESTIGATIONS(U) ARMY ENGINEER DIV NORTH PACIFIC BONNEVILLE OR DIV HYDRAULIC LAB R L JOHNSON ET AL. 2/3

UNCLASSIFIED AUG 84 TR-121-1 F/G 20/4 NL



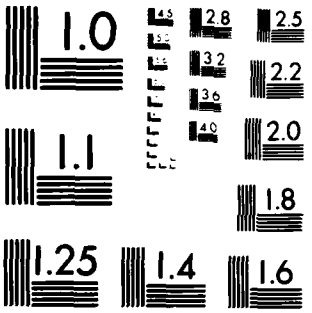
END

DATE FILMED

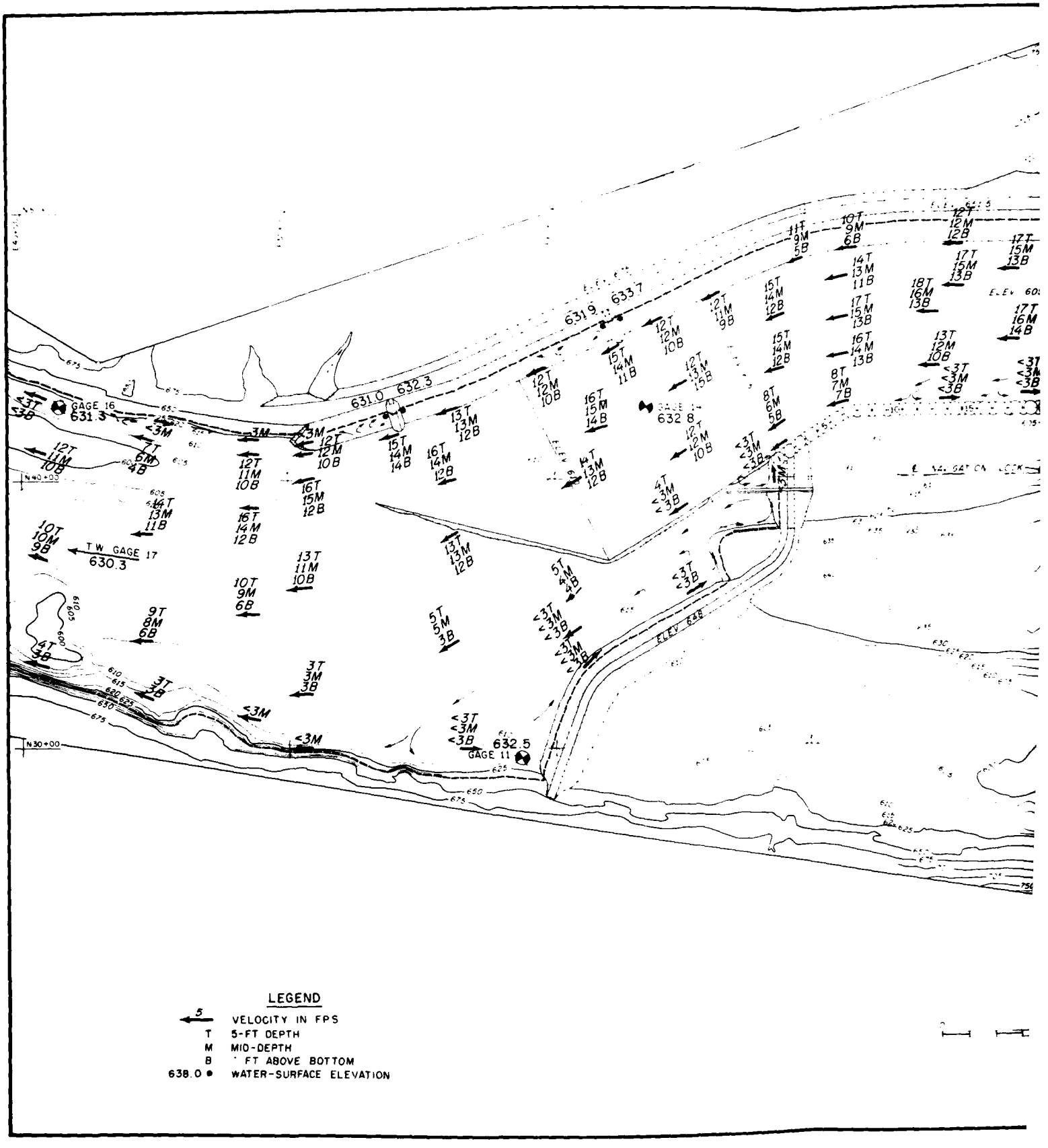
11-84

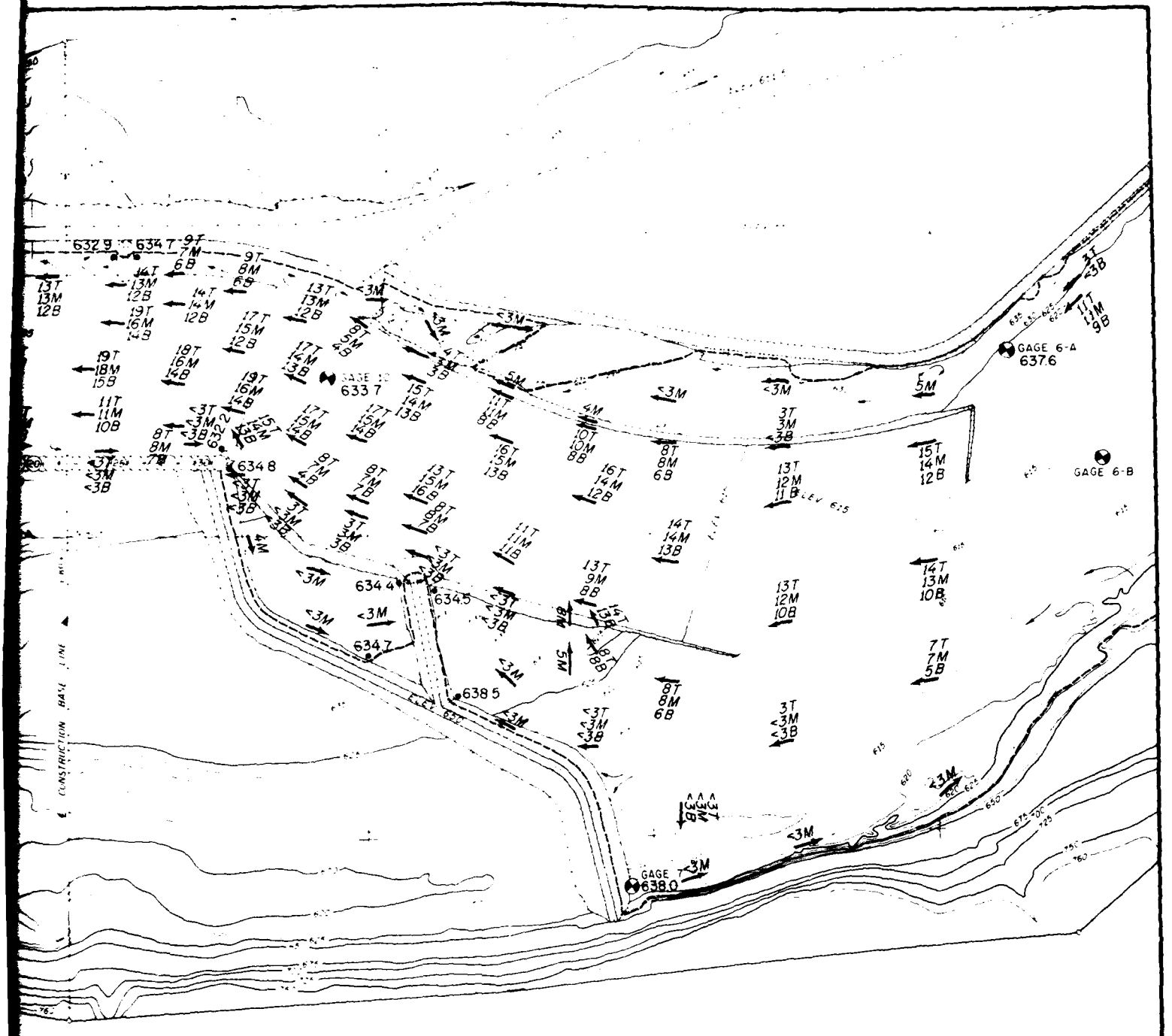
DTIC

CONT



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A


GAGE 16
631.3
631.0
632.3
631.9
633.7
GAGE 14
632.8
TW GAGE 17
630.3
GAGE 11
632.5
N40+00
N30+00
ELEV 646
LEGEND
5 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B FT ABOVE BOTTOM
638.0 WATER-SURFACE ELEVATION



FLOW CONDITIONS

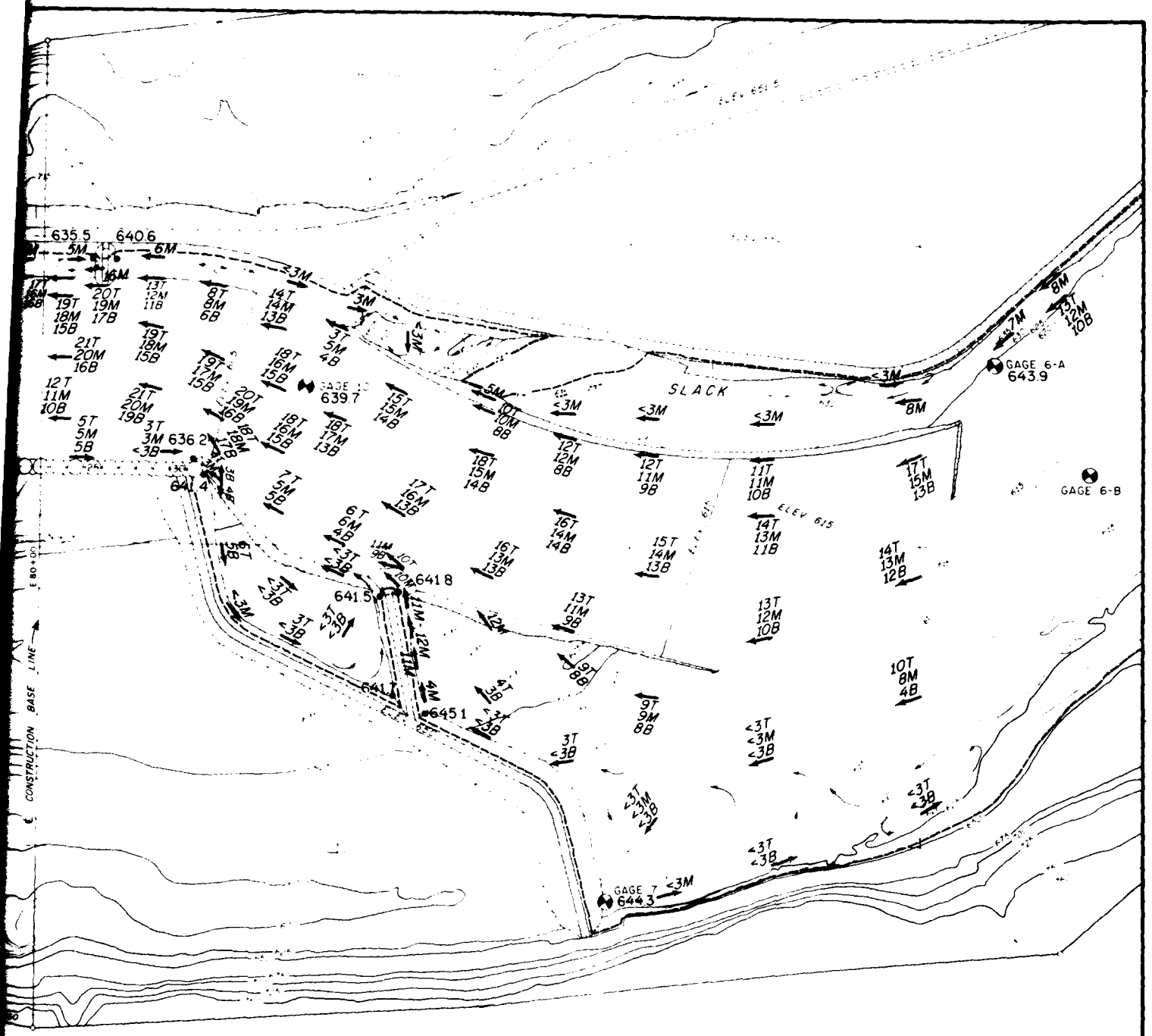
PLAN C DIVERSION CHANNEL ENTRANCE
FIRST-STEP COFFERDAM

RIVER DISCHARGE 200000 CFS

PLATE 23

LEGEND

← 5	VELOCITY IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5-FT ABOVE BOTTOM
634.7 ●	WATER-SURFACE ELEVATION



FLOW CONDITIONS

PLAN C DIVERSION CHANNEL ENTRANCE
FIRST-STEP COFFERDAM

RIVER DISCHARGE 300000 CFS

PLATE 24

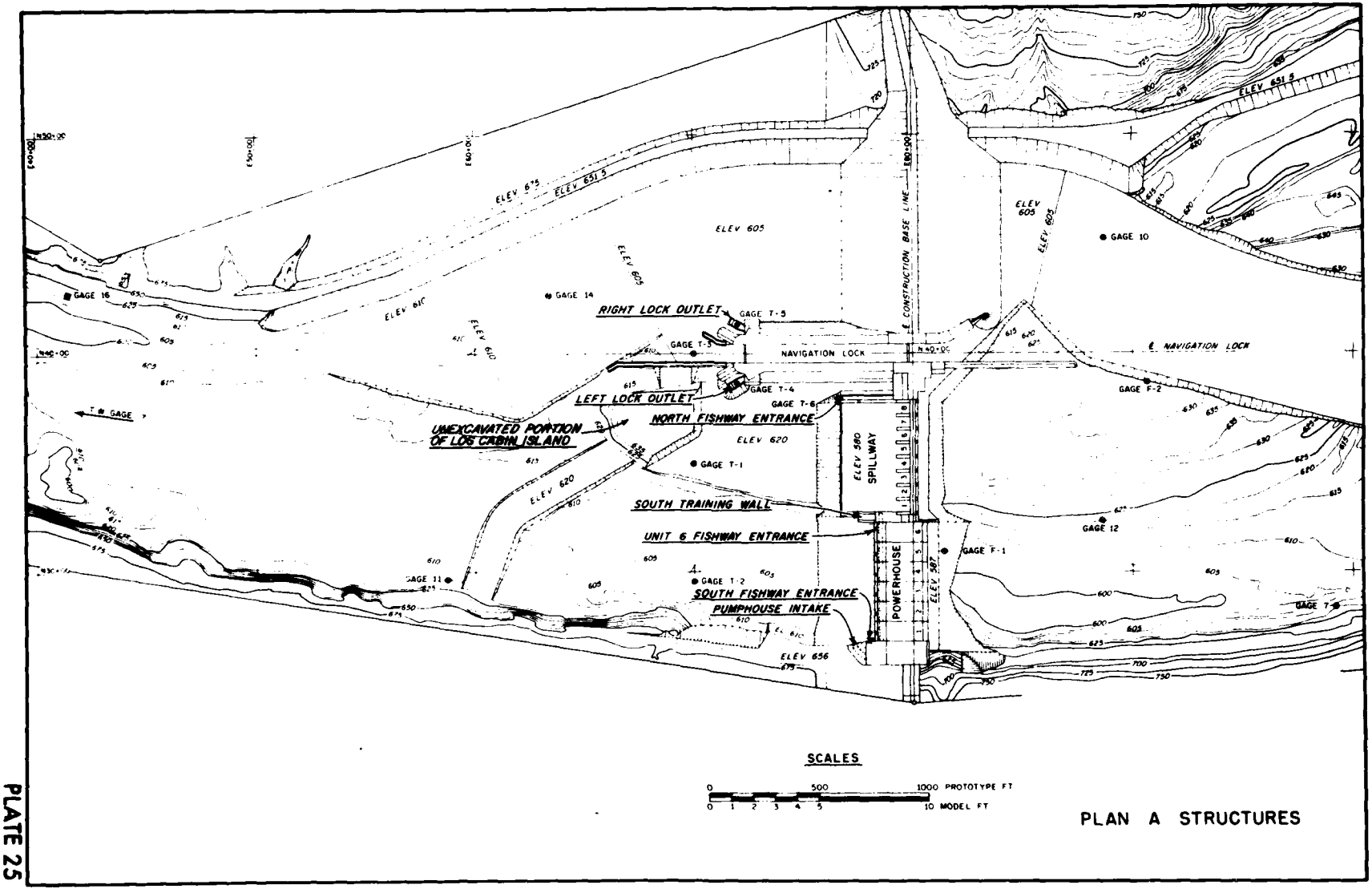
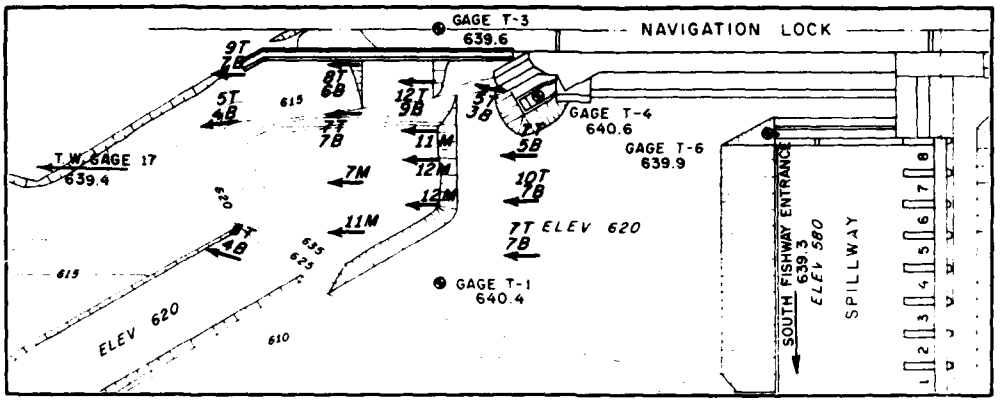
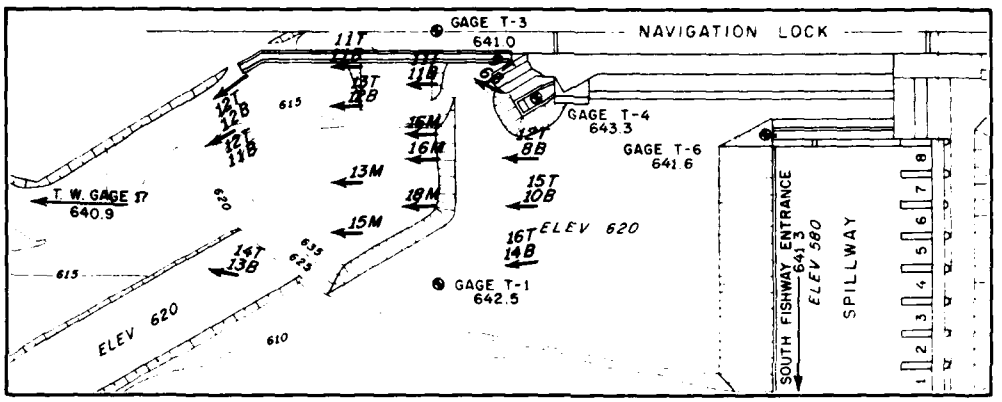


PLATE 25

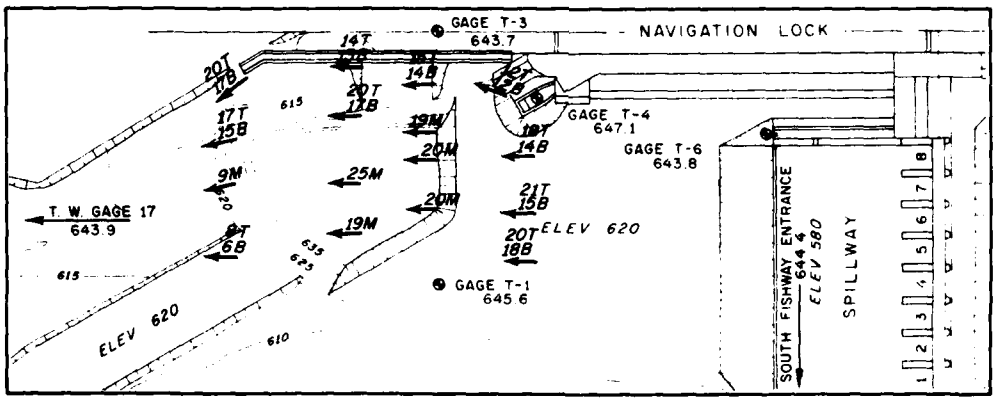
PLAN A STRUCTURES



RIVER DISCHARGE 150000 CFS



RIVER DISCHARGE 225000 CFS



RIVER DISCHARGE 340000 CFS

NOTE

A LAYOUT OF THE ORIGINAL STRUCTURES AND EXCAVATION PLAN IS SHOWN ON PLATE 25

LEGEND

2	VELOCITY IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
633.3	WATER-SURFACE ELEVATIONS

FLOW CONDITIONS

ORIGINAL STRUCTURES AND TAILRACE

PLATE 26

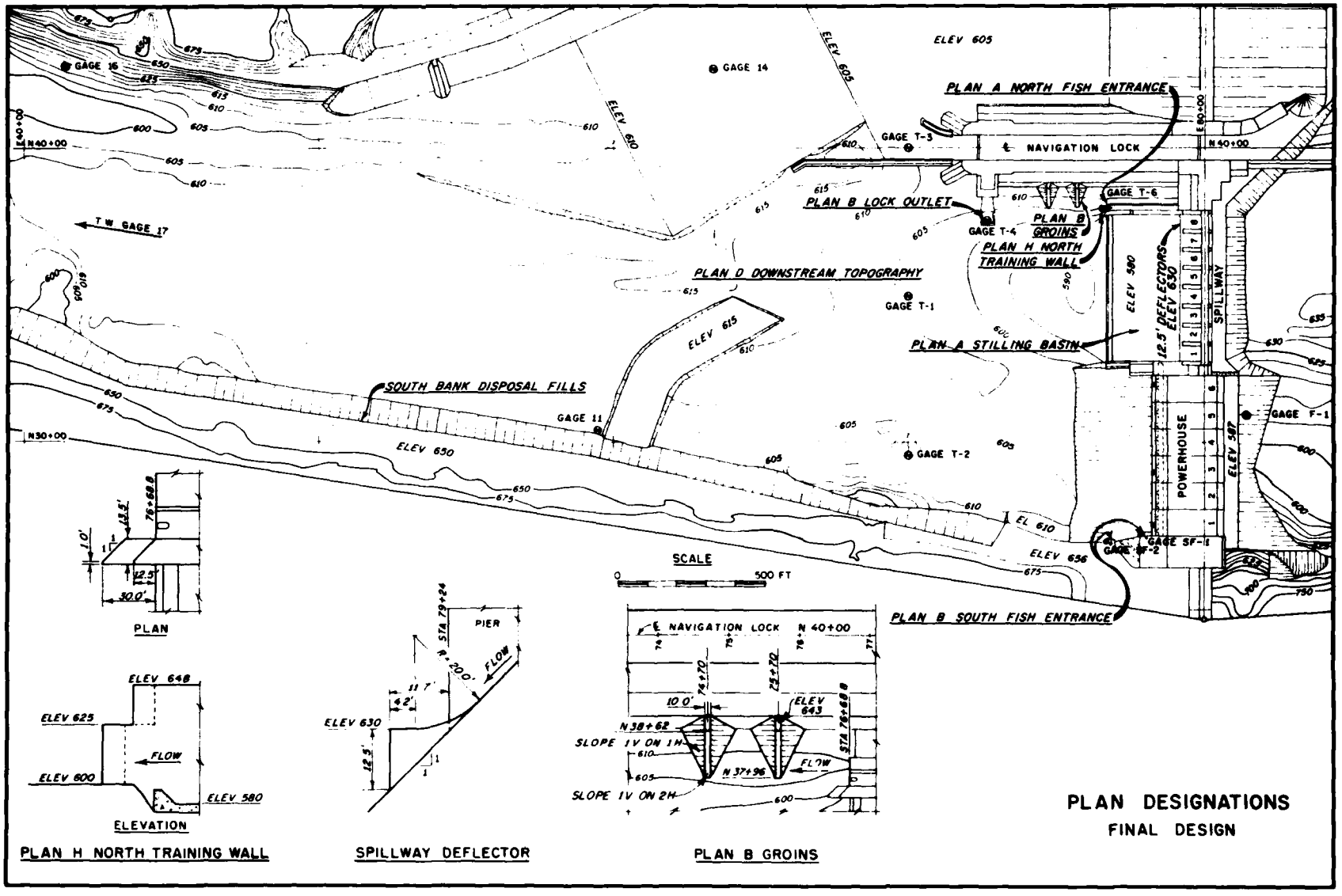
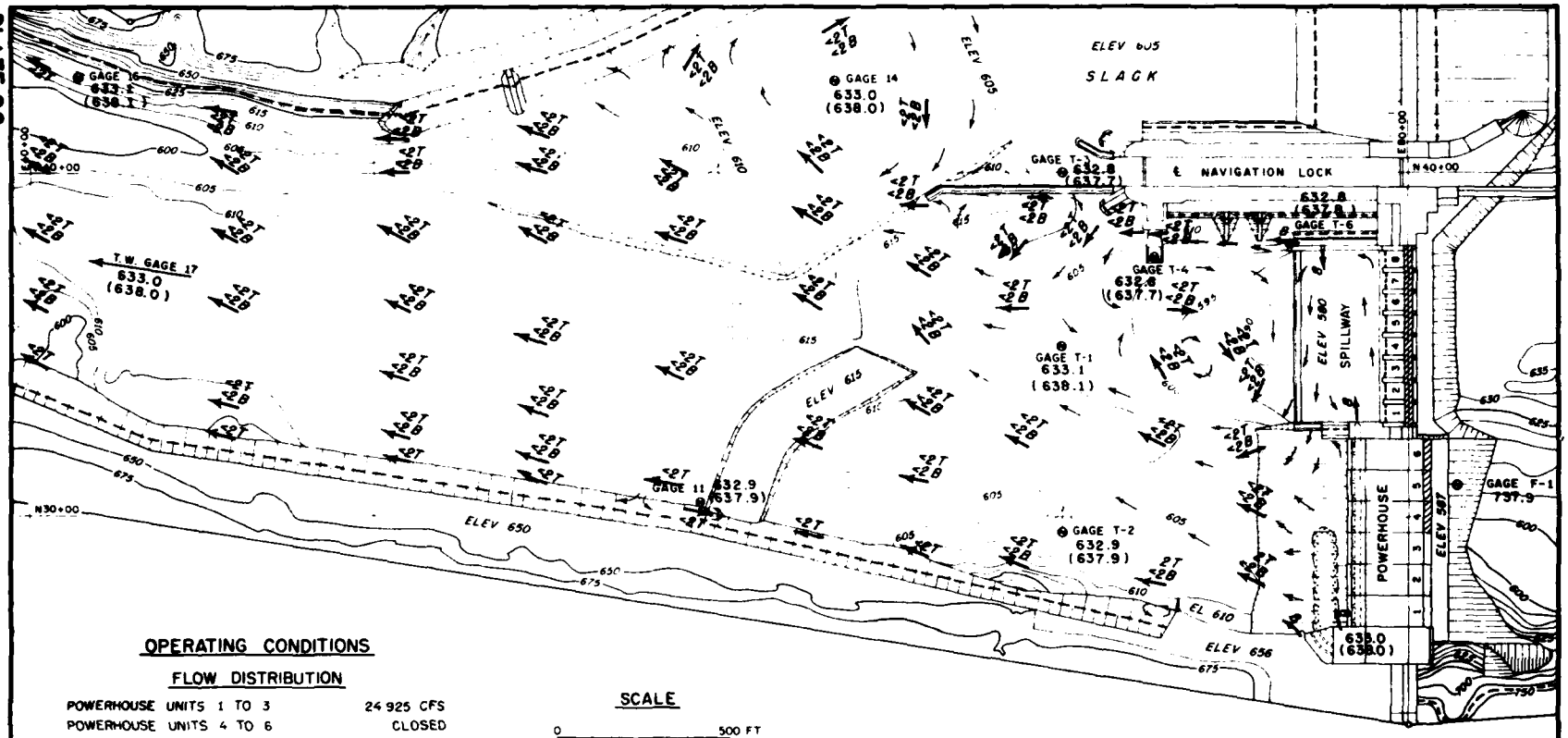


PLATE 27

PLAN DESIGNATIONS
FINAL DESIGN

PLATE 28



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	24 925 CFS
POWERHOUSE UNITS 4 TO 6	CLOSED
SPILLWAY BAYS 1 TO 8	CLOSED
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	500 CFS
UNIT 6 FISHWAY ENTRANCE	500 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	500 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 025 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 500 FT

LEGEND

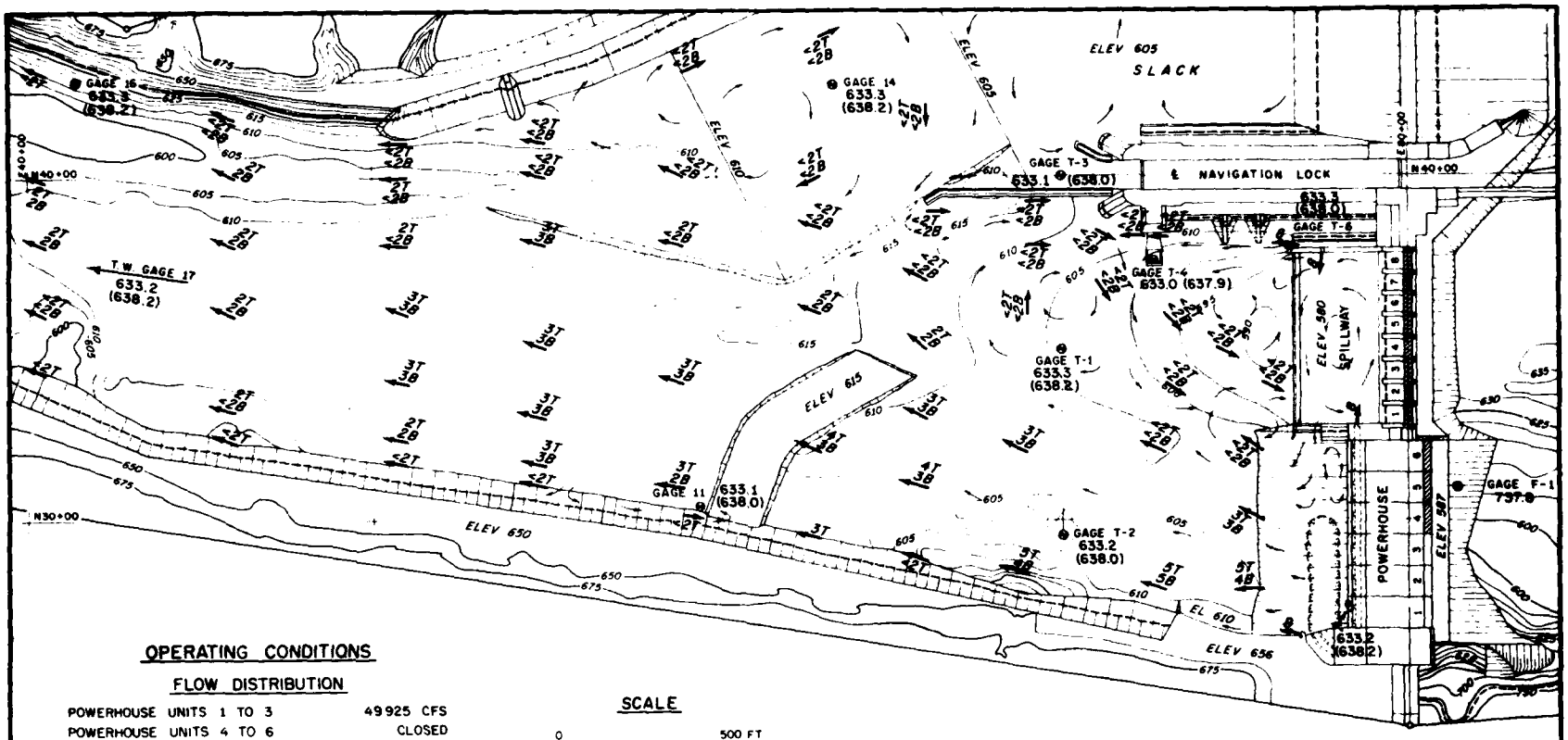
← 2	VELOCITY IN FPS WITH LITTLE GOOSE POOL ELEV 633.0
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
632 9 •	WATER-SURFACE ELEVATION LITTLE GOOSE POOL ELEV 633.0
(638 0)	WATER-SURFACE ELEVATION LITTLE GOOSE POOL ELEV 638 0

FINAL DESIGN

FLOW CONDITIONS

RIVER DISCHARGE 25 000 CFS

POWERHOUSE UNITS 1 TO 3



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	49 925 CFS
POWERHOUSE UNITS 4 TO 6	CLOSED
SPILLWAY BAYS 1 TO 8	CLOSED
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	500 CFS
UNIT 6 FISHWAY ENTRANCE	500 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	500 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 025 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 500 FT

LEGEND

← 3 VELOCITY IN FPS WITH LITTLE GOOSE POOL ELEV 633 0

T 5-FT DEPTH

M MID-DEPTH

B 5 FT ABOVE BOTTOM

633 1 • WATER-SURFACE ELEVATION LITTLE GOOSE POOL ELEV 633 0

(638 2)• WATER-SURFACE ELEVATION LITTLE GOOSE POOL ELEV 638 0

FINAL DESIGN

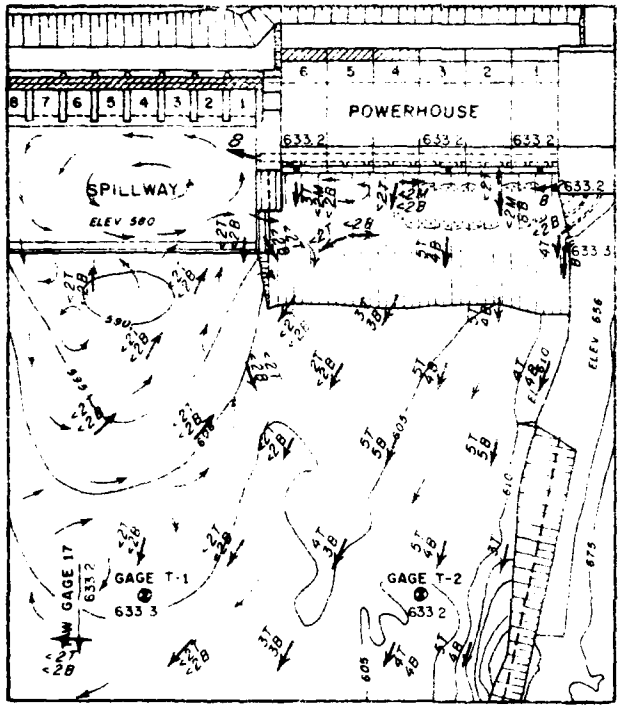
FLOW CONDITIONS

RIVER DISCHARGE 50 000 CFS

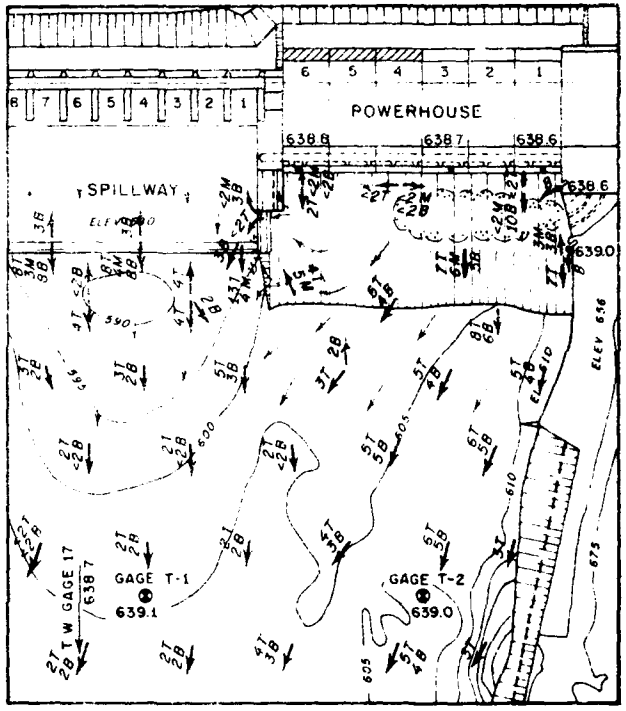
POWERHOUSE UNITS 1 TO 3

PLATE 29

PLATE 30



RIVER DISCHARGE 50 000 CFS
SPILLWAY CLOSED



RIVER DISCHARGE 100 000 CFS
SPILLWAY DISCHARGE 35 725 CFS

LEGEND

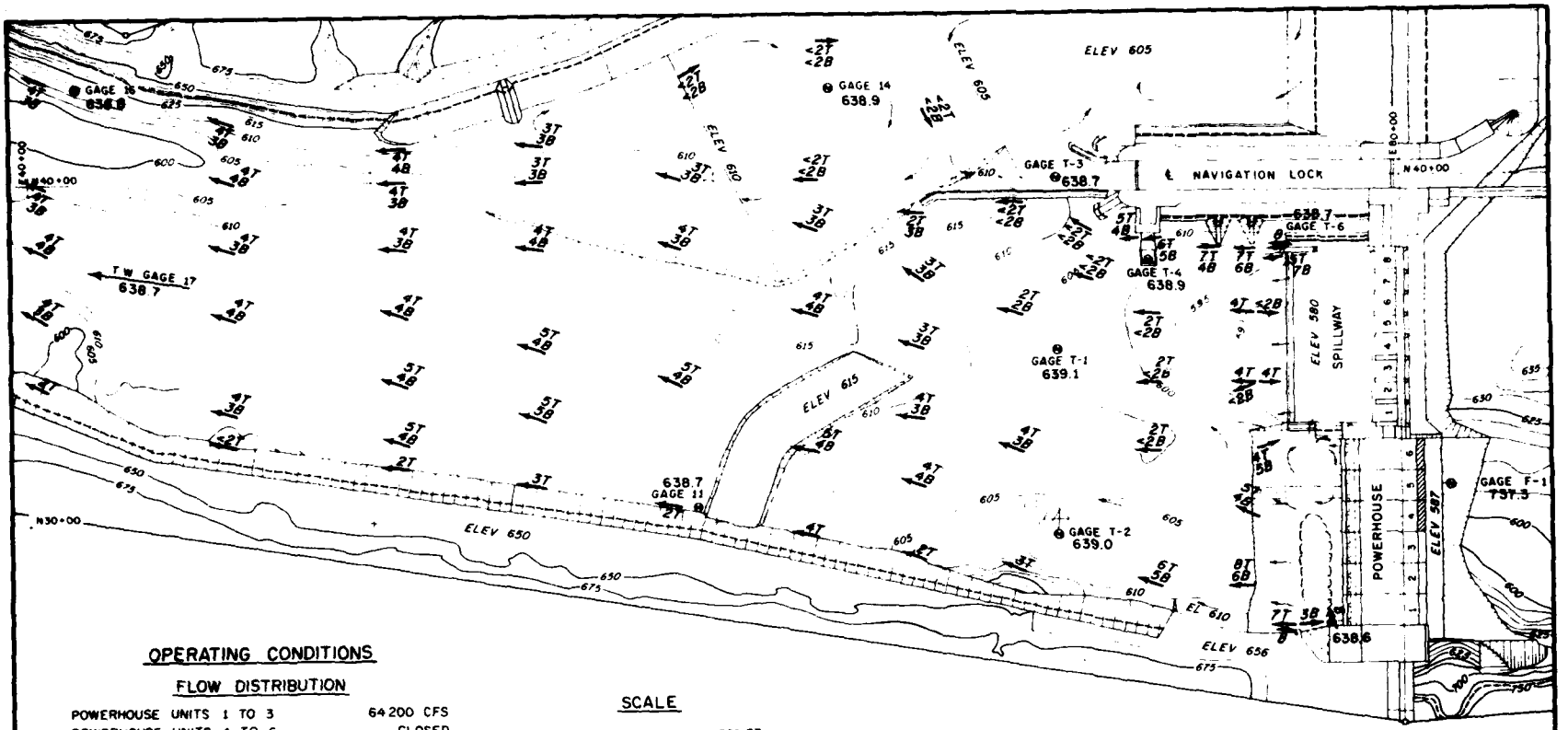
- 2 — VELOCITY IN FPS
- T — 5-FT DEPTH
- M — MID-DEPTH
- B — 5 FT ABOVE BOTTOM
- 633.3 ● — WATER-SURFACE ELEVATIONS

POWERHOUSE UNITS 1 TO 3 OPERATING

FLOW CONDITIONS IN TAILRACE

FINAL STRUCTURES AND EXCAVATION

RIVER DISCHARGES 50 000 AND 100 000 CFS



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	64 200 CFS
POWERHOUSE UNITS 4 TO 6	CLOSED
SPILLWAY BAYS 1 TO 8	35 725 CFS
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	500 CFS
UNIT 6 FISHWAY ENTRANCE	500 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	500 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2025 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 500 FT

LEGEND

5 ← VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
638.7 • WATER-SURFACE ELEVATION

FINAL DESIGN

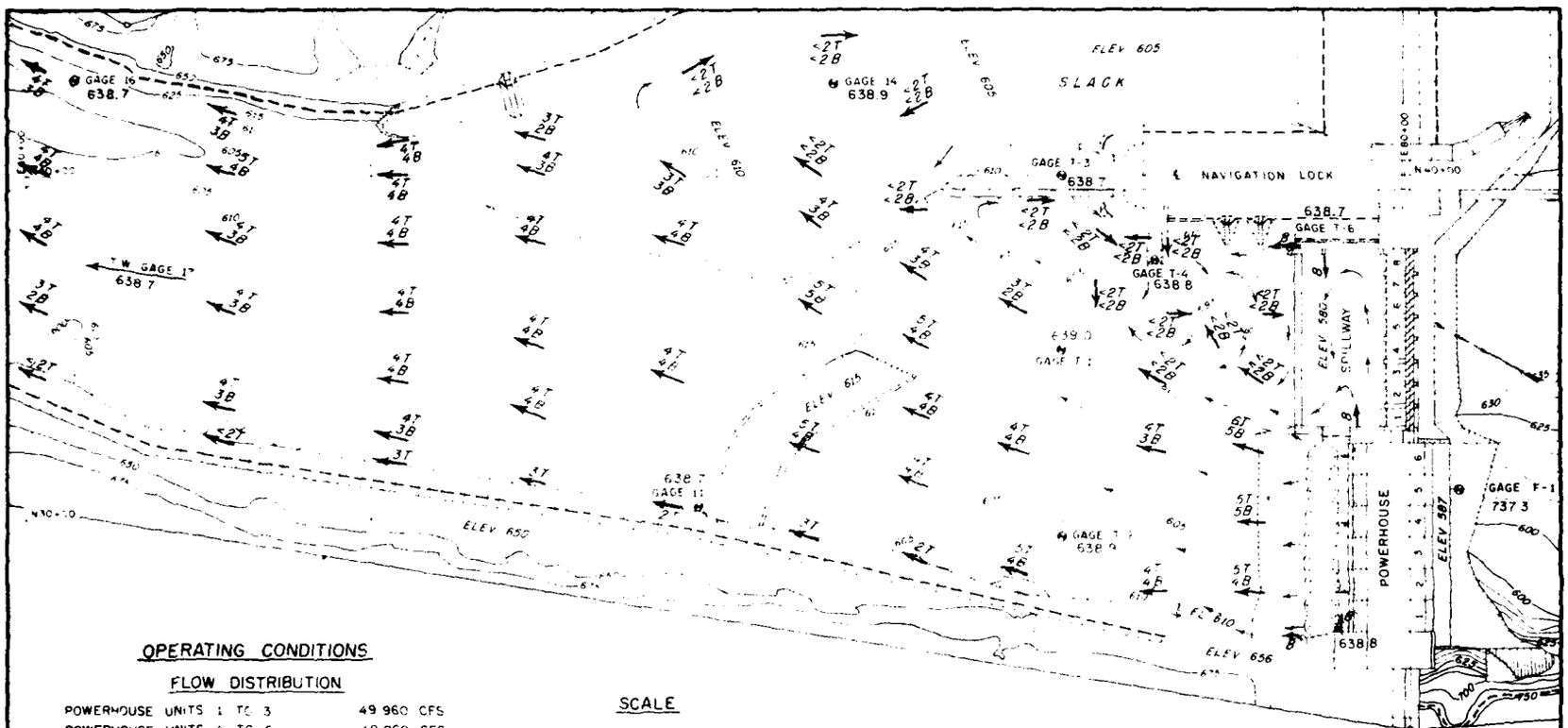
FLOW CONDITIONS

RIVER DISCHARGE 100 000 CFS

POWERHOUSE UNITS 1 TO 3

PLATE 31

PLATE 32



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	49 960 CFS
POWERHOUSE UNITS 4 TO 6	49 960 CFS
SPILLWAY BAYS 1 TO 8	CLOSED
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	500 CFS
UNIT 6 FISHWAY ENTRANCE	500 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	500 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 025 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 500 FT

LEGEND

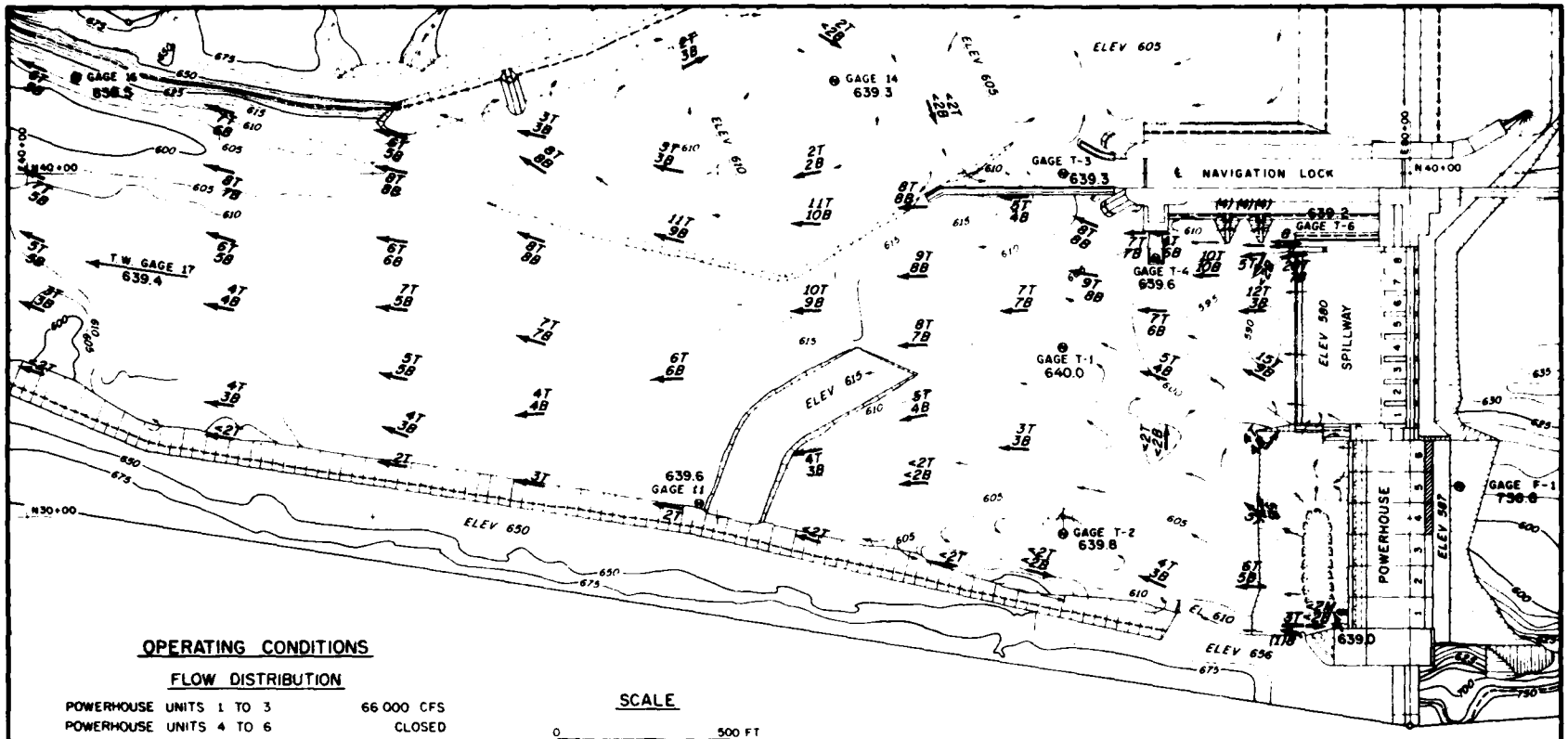
4 T FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
638.7 ● WATER-SURFACE ELEVATION

FINAL DESIGN

FLOW CONDITIONS

RIVER DISCHARGE 100 000 CFS

POWERHOUSE UNITS 1 TO 6



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	66 000 CFS
POWERHOUSE UNITS 4 TO 6	CLOSED
SPILLWAY BAYS 1 TO 8	83 925 CFS
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	840 CFS
UNIT 6 FISHWAY ENTRANCE	600 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	600 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 565 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 500 FT

LEGEND

6 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
639.6 • WATER-SURFACE ELEVATION
(4) WAVE HEIGHTS IN FEET

FINAL DESIGN

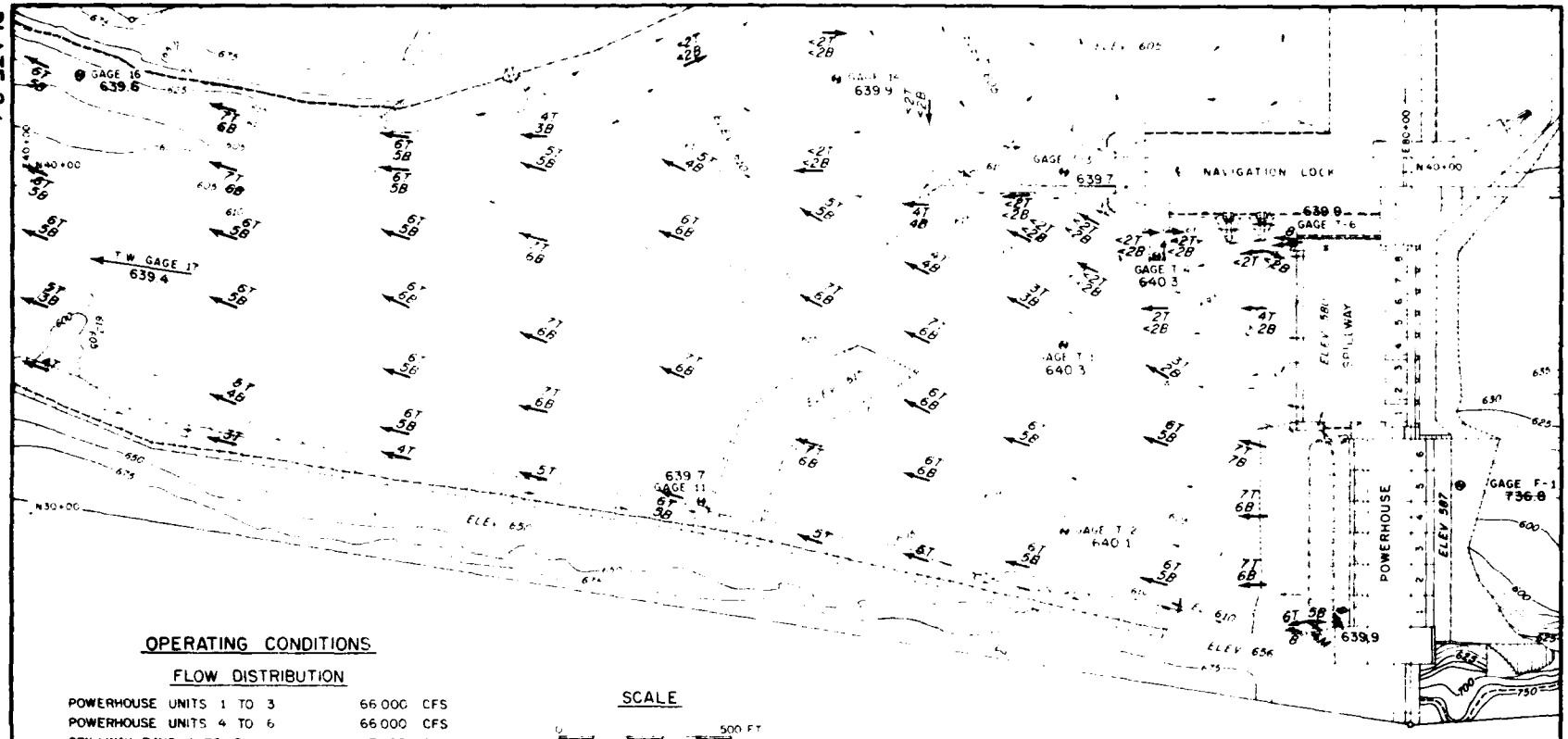
FLOW CONDITIONS

RIVER DISCHARGE 150 000 CFS

POWERHOUSE UNITS 1 TO 3

PLATE 33

PLATE 34



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	66 000	CFS
POWERHOUSE UNITS 4 TO 6	66 000	CFS
SPILLWAY BAYS 1 TO 8	17 925	CFS
FISH LADDER	75	CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	840	CFS
UNIT 6 FISHWAY ENTRANCE	600	CFS
POWERHOUSE FISH COLLECTION SYSTEM	600	CFS
SOUTH FISHWAY ENTRANCE	600	CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 565	CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 — 500 FT

LEGEND

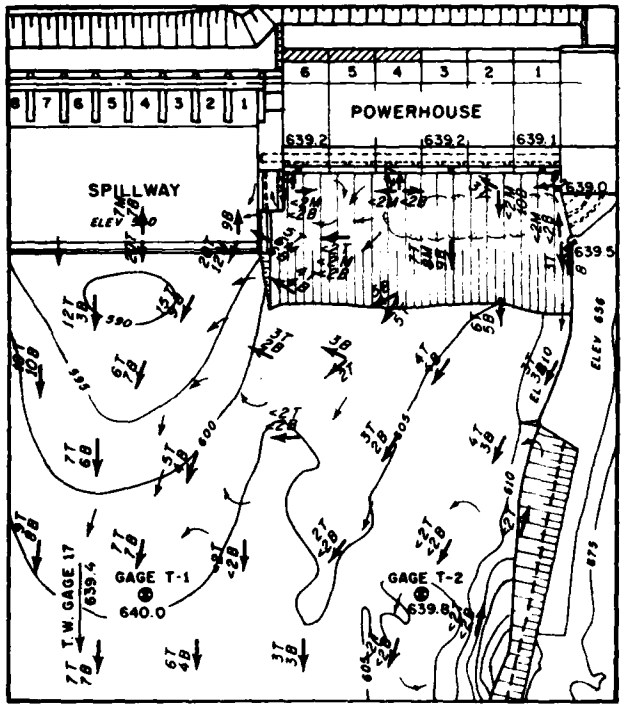
6 — VELOCITY IN FPS
T 5 FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
639 7 • WATER SURFACE ELEVATION

FINAL DESIGN

FLOW CONDITIONS

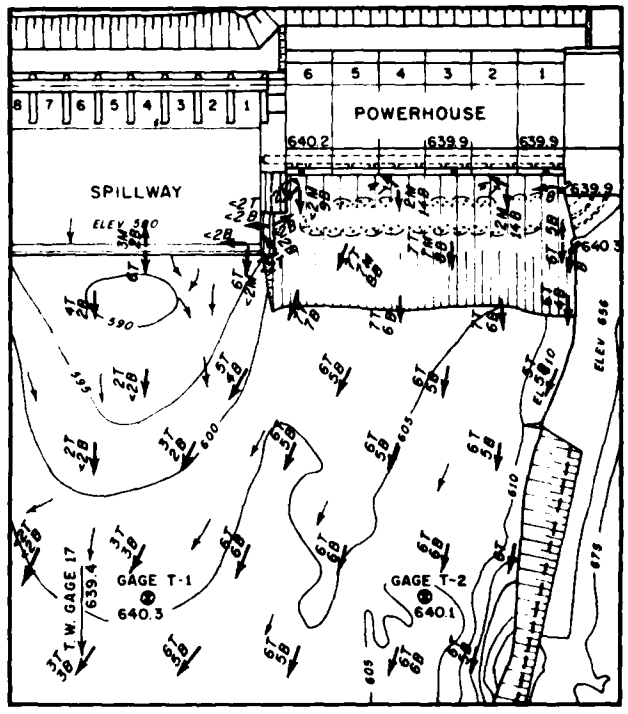
RIVER DISCHARGE 150 000 CFS

POWERHOUSE UNITS 1 TO 6



POWERHOUSE UNITS 1 TO 3 OPERATING

POWERHOUSE DISCHARGE 66 000 CFS
SPILLWAY DISCHARGE 83 925 CFS



POWERHOUSE UNITS 1 TO 6 OPERATING

POWERHOUSE DISCHARGE 132 000 CFS
SPILLWAY DISCHARGE 17 925 CFS

LEGEND

- 6 — VELOCITY IN FPS
- T — 5-FT DEPTH
- M — MID-DEPTH
- B — 5 FT ABOVE BOTTOM
- 639.8 — WATER-SURFACE ELEVATIONS

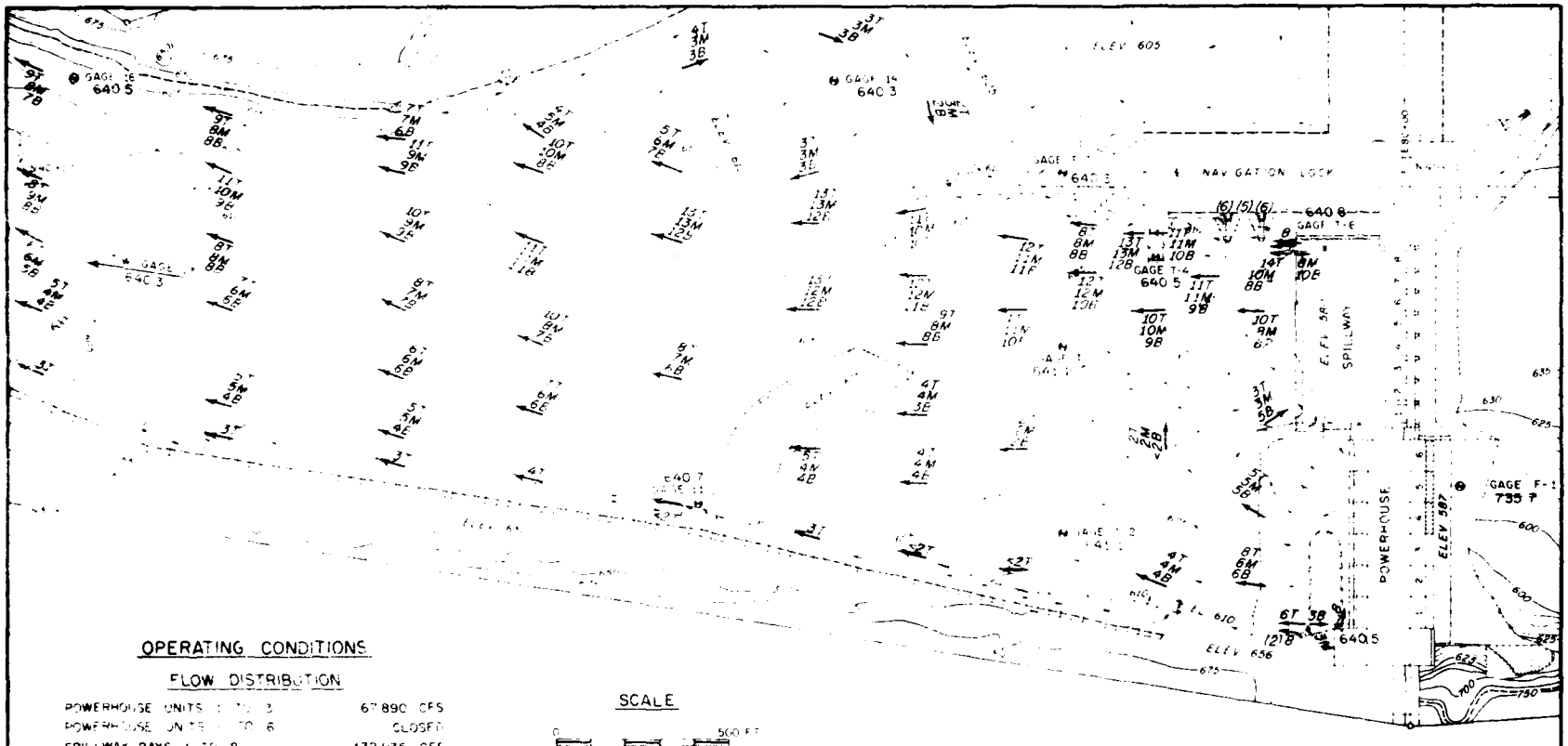
FLOW CONDITIONS IN TAILRACE

FINAL STRUCTURES AND EXCAVATION

RIVER DISCHARGE 150 000 CFS

PLATE 35

PLATE 36



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	67 890 CFS
POWERHOUSE UNITS 4 TO 6	CLOSED
SPILLWAY BAYS 1 TO 8	132 035 CFS
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	840 CFS
UNIT 6 FISHWAY ENTRANCE	600 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	600 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 565 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 500 FT

LEGEND

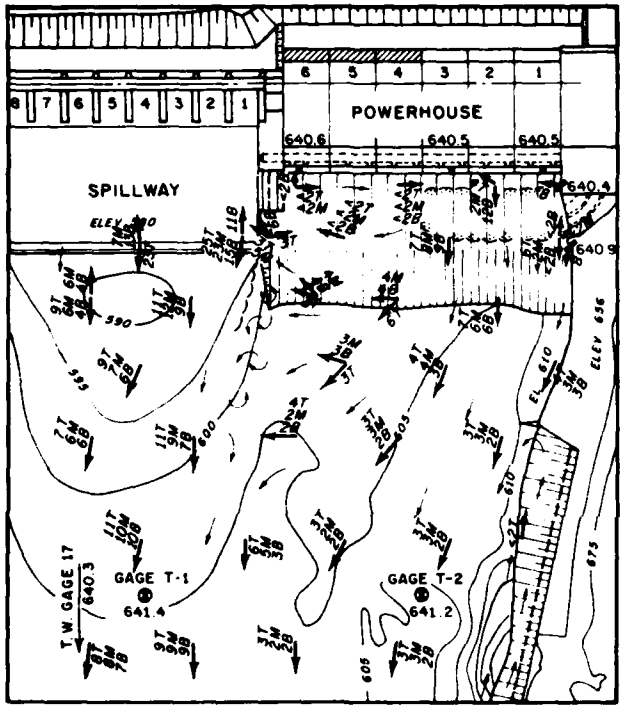
- T 5-FT DEPTH
- M MID-DEPTH
- B 5 FT ABOVE BOTTOM
- 640.7 • WATER-SURFACE ELEVATION
- (5) WAVE HEIGHTS IN FEET

FINAL DESIGN

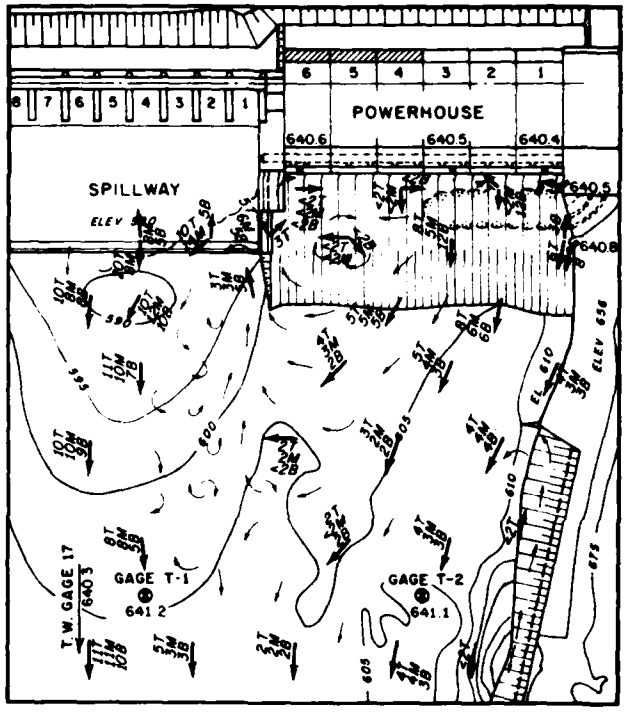
FLOW CONDITIONS

RIVER DISCHARGE 200 000 CFS

POWERHOUSE UNITS 1 TO 3



ADJUSTED SPILLWAY OPERATION



UNIFORM SPILLWAY OPERATION

BAY	1	24 230 CFS
BAY	2	18 300 CFS
BAYS	3 TO 7	14 600 CFS
BAY	8	16 505 CFS

LEGEND

- 4 — VELOCITY IN FPS
- T — 5-FT DEPTH
- M — MID-DEPTH
- B — 5 FT ABOVE BOTTOM
- 640.6 ● — WATER-SURFACE ELEVATIONS

POWERHOUSE UNITS 1 TO 3 OPERATING

FLOW CONDITIONS IN TAILRACE

FINAL STRUCTURES AND EXCAVATION

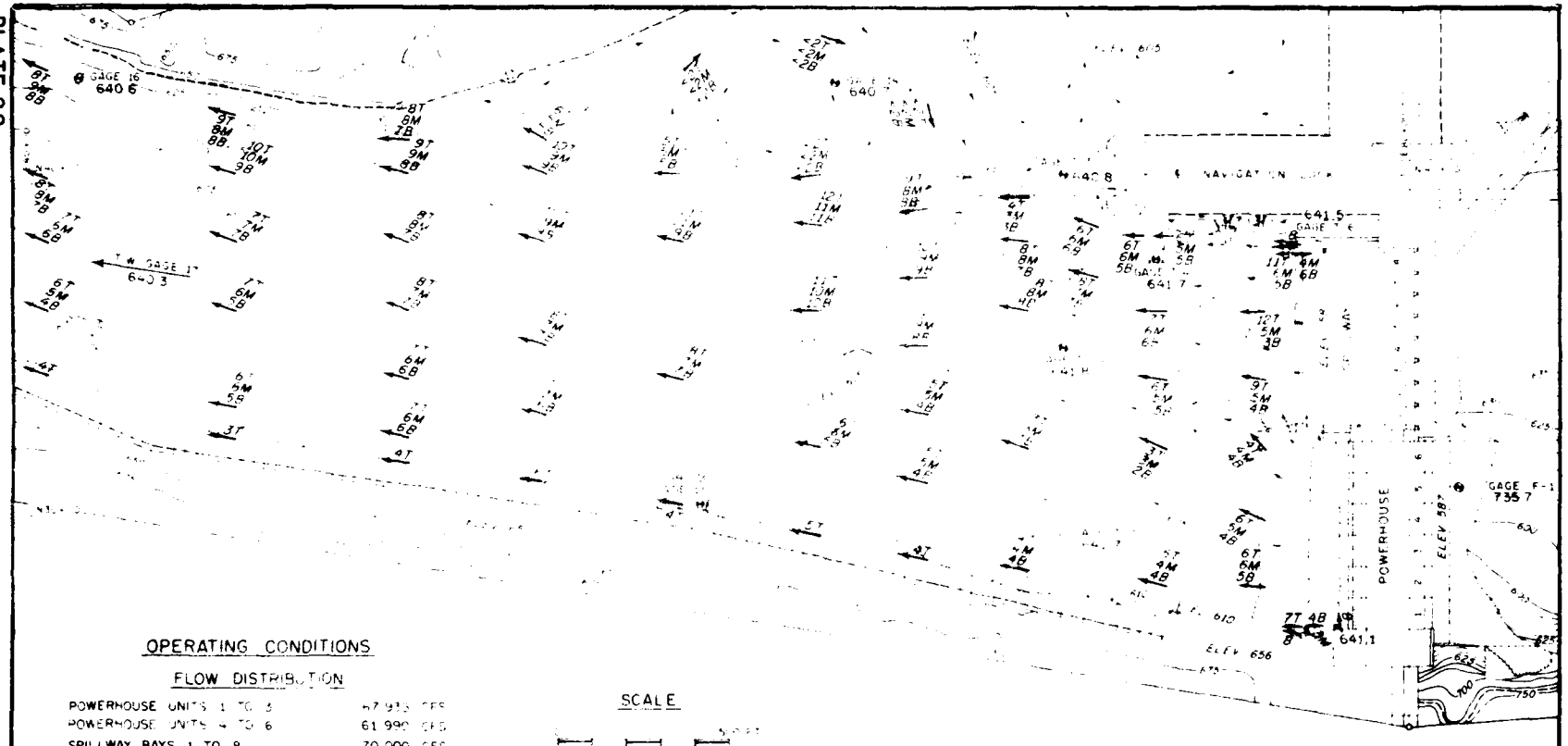
ADJUSTED AND UNIFORM SPILLWAY OPERATION

RIVER DISCHARGE 200 000 CFS

SPILLWAY DISCHARGE 132 000 CFS

PLATE 37

PLATE 38



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	67 935 CFS
POWERHOUSE UNITS 4 TO 6	61 990 CFS
SPILLWAY BAYS 1 TO 8	70 000 CFS
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	840 CFS
UNIT 6 FISHWAY ENTRANCE	600 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	600 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 565 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

LEGEND

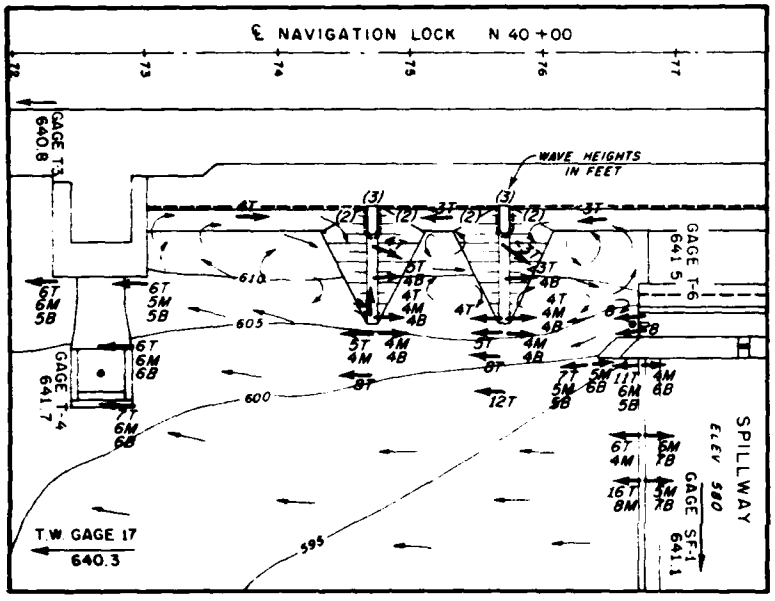
5 FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
641 1 • WATER SURFACE ELEVATION

FINAL DESIGN

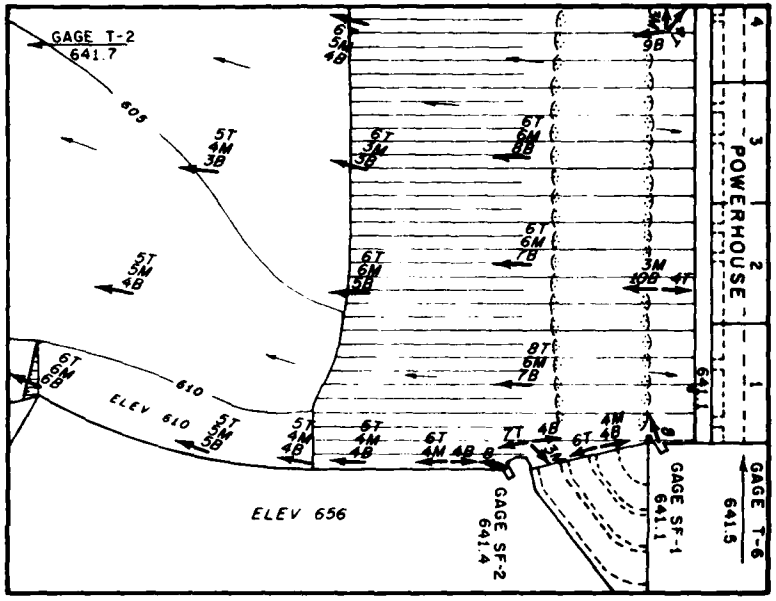
FLOW CONDITIONS

RIVER DISCHARGE 200 000 CFS

POWERHOUSE UNITS 1 TO 6



NORTH FISHWAY ENTRANCE



SOUTH FISHWAY ENTRANCE

LEGEND

- 4 — VELOCITY IN FPS
- T — 5-FT DEPTH
- M — MID-DEPTH
- B — 5 FT ABOVE BOTTOM
- 640.7 ● — WATER-SURFACE ELEVATIONS

POWERHOUSE UNITS 1 TO 6 OPERATING

FLOW CONDITIONS AT FISHWAY ENTRANCE

FINAL STRUCTURES AND EXCAVATION

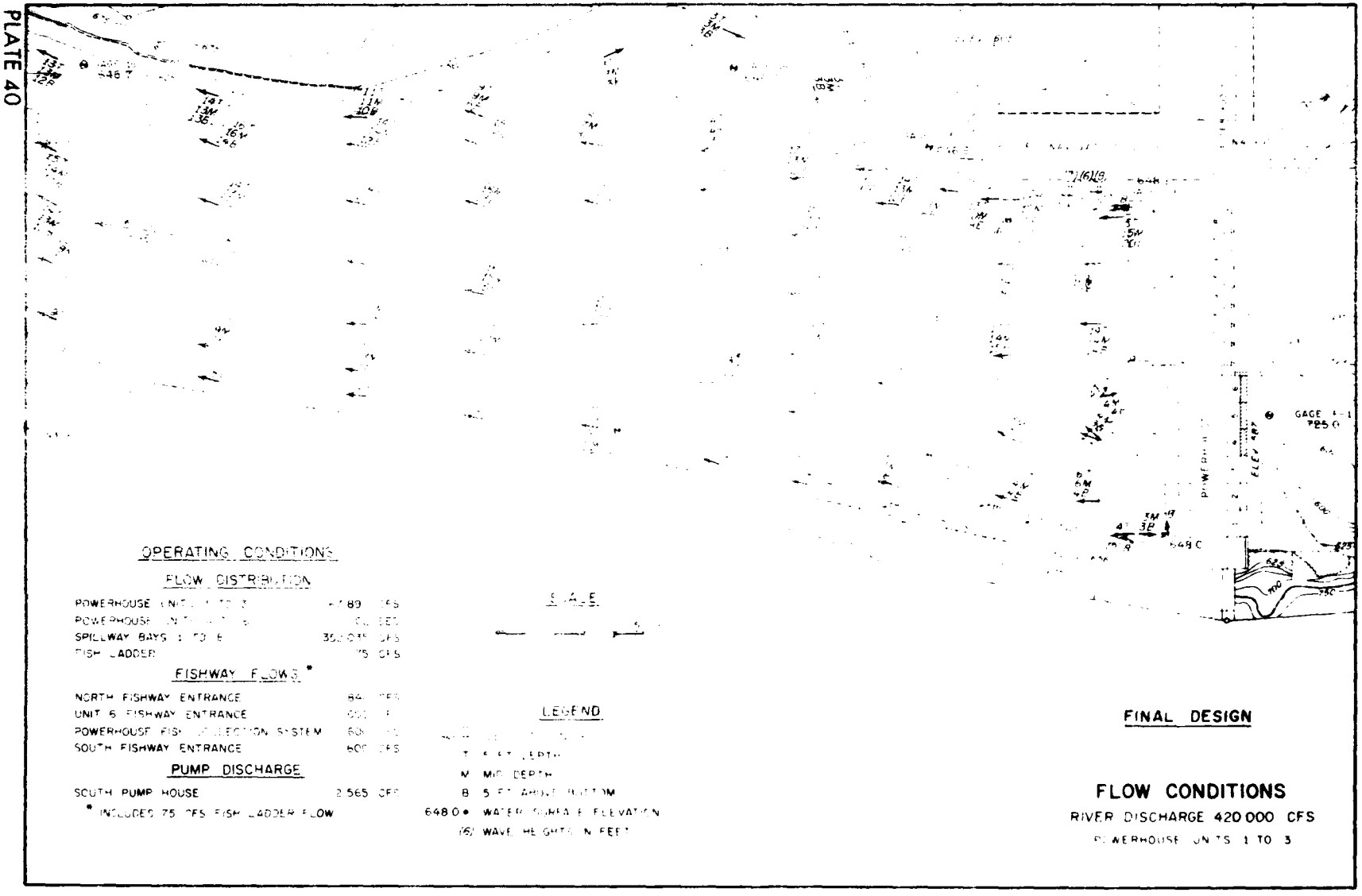
UNIFORM SPILLWAY OPERATION

RIVER DISCHARGE 200 000 CFS

SPILLWAY DISCHARGE 70 000 CFS

PLATE 39

PLATE 40



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	47 89 CFS
POWERHOUSE UNITS 4 TO 6	CLOSED
SPILLWAY BAYS 1 TO 8	35 [illegible] CFS
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	84 CFS
UNIT 6 FISHWAY ENTRANCE	[illegible] CFS
POWERHOUSE FISH COLLECTION SYSTEM	60[illegible] CFS
SOUTH FISHWAY ENTRANCE	600 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 565 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

LEGEND

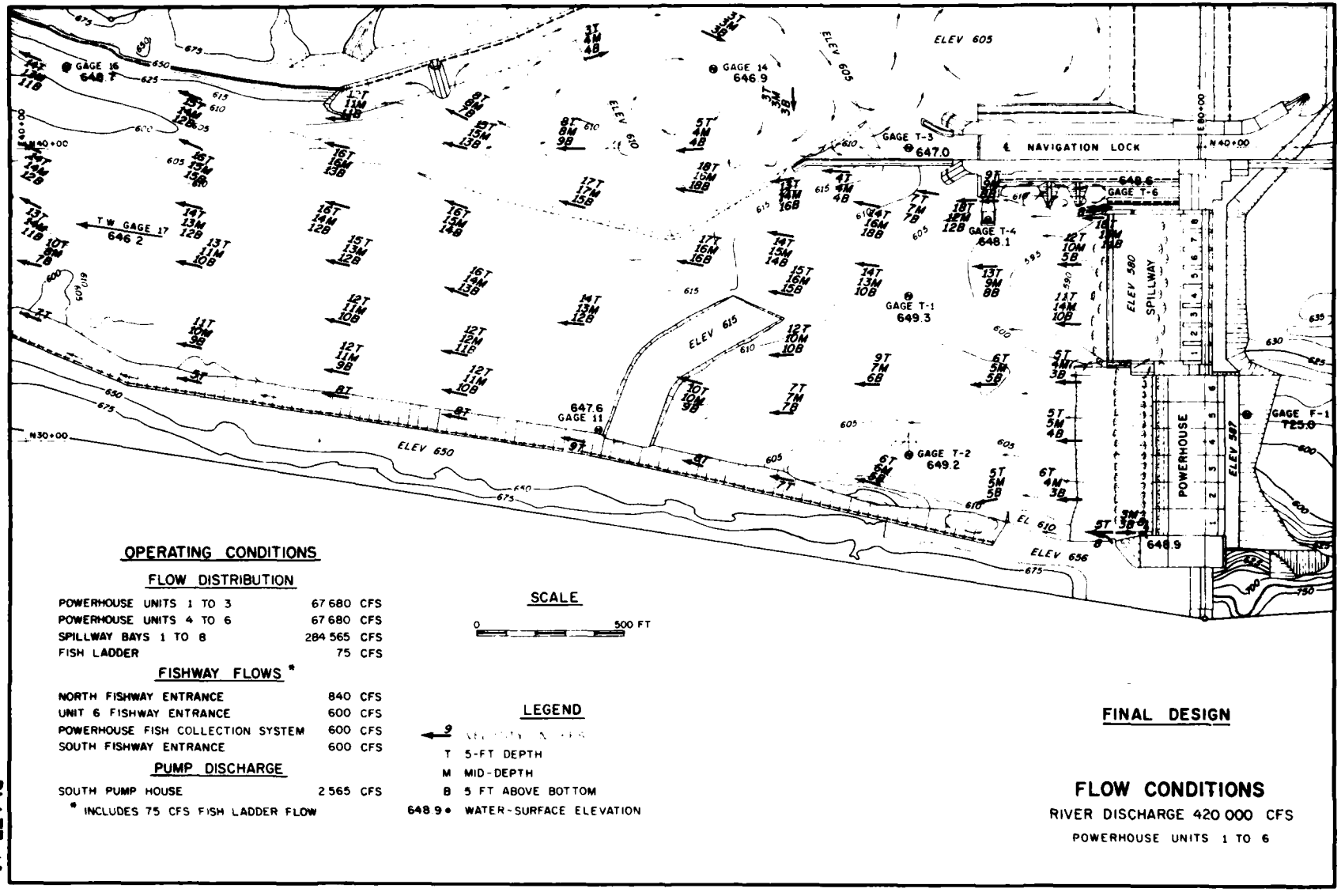
F FEET DEPTH
M MID DEPTH
B 5 FT ABOVE BOTTOM
648.0 ● WATER SURFACE ELEVATION
(6) WAVE HEIGHTS IN FEET

FINAL DESIGN

FLOW CONDITIONS

RIVER DISCHARGE 420 000 CFS

POWERHOUSE UNITS 1 TO 3



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	67 680 CFS
POWERHOUSE UNITS 4 TO 6	67 680 CFS
SPILLWAY BAYS 1 TO 8	284 565 CFS
FISH LADDER	75 CFS

FISHWAY FLOWS *

NORTH FISHWAY ENTRANCE	840 CFS
UNIT 6 FISHWAY ENTRANCE	600 CFS
POWERHOUSE FISH COLLECTION SYSTEM	600 CFS
SOUTH FISHWAY ENTRANCE	600 CFS

PUMP DISCHARGE

SOUTH PUMP HOUSE	2 565 CFS

* INCLUDES 75 CFS FISH LADDER FLOW

SCALE

0 500 FT

LEGEND

9 VELOCITY IN FPS

T 5-FT DEPTH

M MID-DEPTH

B 5 FT ABOVE BOTTOM

648.9 WATER-SURFACE ELEVATION

FINAL DESIGN

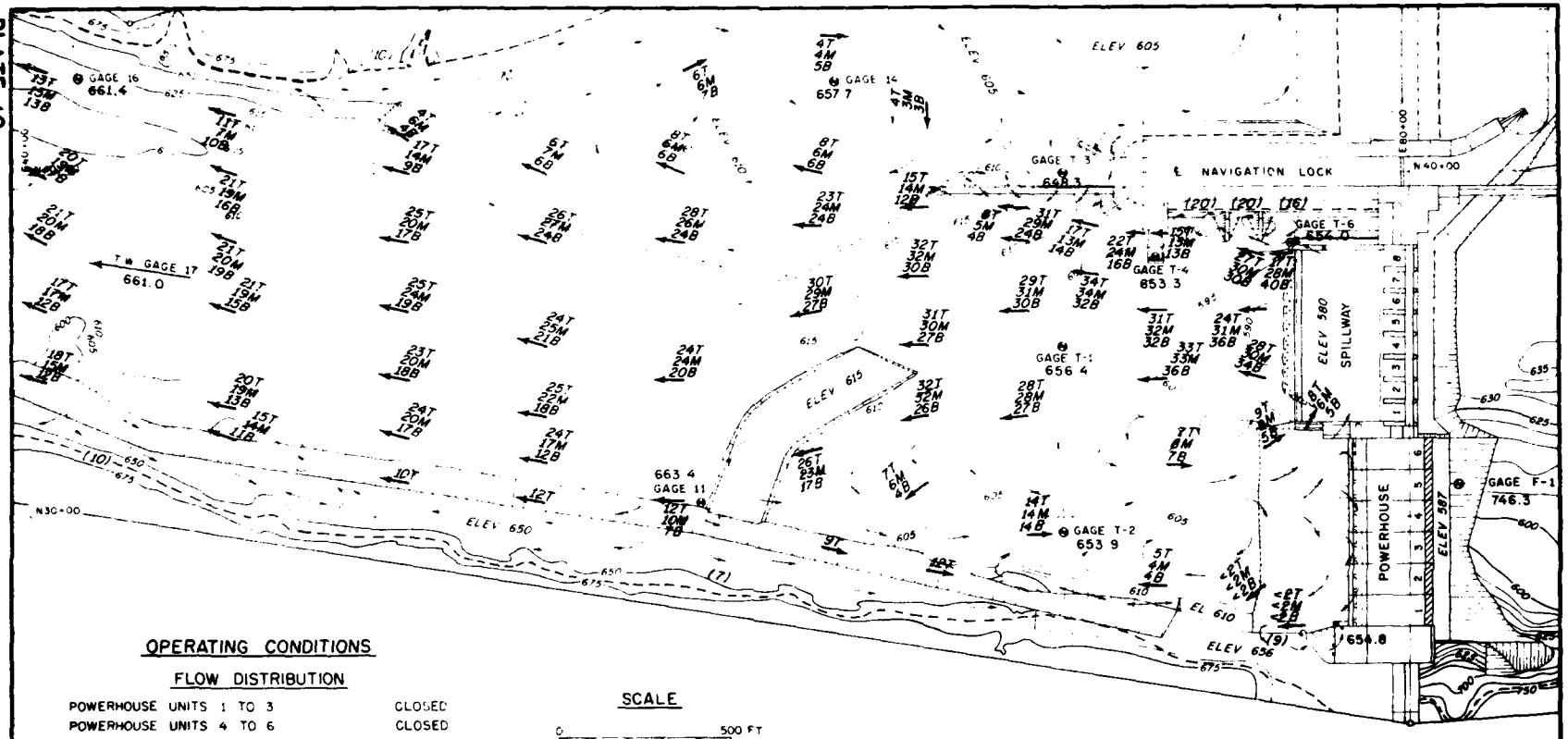
FLOW CONDITIONS

RIVER DISCHARGE 420 000 CFS

POWERHOUSE UNITS 1 TO 6

PLATE 41

PLATE 42



OPERATING CONDITIONS

FLOW DISTRIBUTION

POWERHOUSE UNITS 1 TO 3	CLOSED
POWERHOUSE UNITS 4 TO 6	CLOSED
SPILLWAY BAYS 1 TO 8	850 000 CFS
FISH LADDER	CLOSED

FISHWAY FLOWS

NORTH FISHWAY ENTRANCE	CLOSED
UNIT 6 FISHWAY ENTRANCE	CLOSED
POWERHOUSE FISH COLLECTION SYSTEM	CLOSED
SOUTH FISHWAY ENTRANCE	CLOSED

PUMP DISCHARGE

SOUTH PUMP HOUSE	CLOSED

SCALE

0 500 FT

LEGEND

12 VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
654.8 • WATER-SURFACE ELEVATION
(10) WAVE HEIGHTS IN FEET

FINAL DESIGN

FLOW CONDITIONS

RIVER DISCHARGE 850 000 CFS

SPILLWAY FLOW ONLY

APPENDIX A
SLOTTED BULKHEAD
AT LOWER GRANITE DAM AND
CONTRACT BULKHEADS FOR LITTLE GOOSE DAM

Purpose of Model

A1. Highly aerated and turbulent flow over the spillways and into deep stilling basins of the lower Snake and Columbia River dams increase the dissolved nitrogen level of the rivers to a supersaturated state considered hazardous to migrating fish. Because powerhouse flows undergo little change in nitrogen level, similar flows through powerhouse skeleton units were proposed as a method to reduce undesirable nitrogen entraining characteristics associated with spillway releases. Although skeleton units are only designed to pass diversion flows under low heads, it appeared possible to throttle flows under full reservoir head to the approximate discharge of an operating unit without jeopardizing the structural integrity of the skeleton units. The general purpose of the model was to evaluate performance and effectiveness of various methods f throttling flow using gates and bulkhead which would pass a maximum unit discharge with minimum air entrainment. Similar model studies were conducted for Ice Harbor and John Day Dams. Results of these tests are available at the Waterways Experiment Station, Vicksburg, Mississippi*.

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* NPDEN-WC-L letter dated 1 June 1972, subject: Ice Harbor Skeleton Unit Model, Slotted Bulkhead Tests, and NPDEN-WC-L letter dated 12 July 1972, subject: John Day Skeleton Unit Model, Slotted Bulkhead Tests.

Description of Model

A2. A single skeleton unit (three intakes) model (plates A1 and A2 and photographs A1 through A4) was constructed in a brick flume with glass viewing windows. The 1:40-scale model was constructed of waterproofed wood, plastic, and molded shapes painted with epoxy paint. Approximately 700 feet of the adjustable forebay and 1,500 feet of tailrace were constructed of waterproofed wood and plastic. For better observation of the flow conditions causing upwelling in the operating gate slots, a simplified 1:40-scale model of only one bay of the intake was constructed with a clear plastic side. Since the skeleton bays at Little Goose Dam are identical to those of Lower Granite Dam, the model was also used for the Little Goose Dam contract bulkhead tests. Water used for the model was recirculated by pump from storage tanks and was measured by a calibrated orifice in the supply line. Standard laboratory procedures were used to measure water surface elevations, pressures, velocities, and other related data.

Tests and Results

A3. The original-design criteria used in development of the concept was that the skeleton bay must pass approximately 22,000 cfs with forebay and tailwater elevations of 737 and 638, respectively, without entraining, and forcing, air into solution. The hydraulic head on the downstream wall of the skeleton bay could not exceed 10 feet, while flow velocities of at least 15 fps were required in the draft tubes to block fish passage. Initially, the operating gates were tested as a flow control. Subsequent tests were made using the operating gates in combination with stoplogs in the gate and intake bulkhead slots. Based on the results of these tests, bulkheads with

orifice slots were developed. The tests were expanded to provide design data so that full-scale orifice bulkheads for one skeleton unit could be built and tested at Little Goose Dam.

Preliminary Studies

A4. During preliminary studies, five flow-control plans as shown on plate A3 were investigated. Flow control by the operating gates alone caused excessive upwelling on the downstream wall of the skeleton bay and large amounts of air were entrained by the accompanying turbulence. In an attempt to direct the flow downward toward the draft tube to reduce turbulence, various combinations of stoplogs were placed in both the bulkhead and operating gate slots with flow being controlled by the operating gate; however, none of the combinations tested was totally successful. A design utilizing four stoplogs in each intake bay with each log having six 1-foot-high by 5-foot-wide slots concentrated the flow and created excessive turbulence in the skeleton bay. Bulkheads placed in the bulkhead slots with orifices over the full height were tested--initially round orifices were tried and then narrow (2½-inch-high) slots spaced vertically 13½ inches apart were tested. The round orifices were not satisfactory because they caused excessive aeration and turbulence in the skeleton bay. The slots effectively reduced turbulence and aeration, but the discharge (17,400 cfs) was less than desired and the narrow slots were considered infeasible for the prototype because trash passing through the 5½-inch bar spacing of the intake trash rack could plug the narrower slots. Removal of the mass concrete block in the skeleton bay between elevations 553 and 578 (plates A1 and A2) caused only minor changes in flow patterns and negligible reduction in turbulence.

Initial Slotted Bulkhead Plans

A5. Based on results of the preliminary studies, further development of the slotted bulkhead concept appeared warranted. To avoid the trash problems expected with the 2½-inch-high slots, 9- and 6-inch-high slots, as well as 12-inch-diameter orifices, were tested. Tests indicated that to prevent air entrainment only the lower 40 feet of the bulkhead should contain openings. Eighteen rows of three 6-inch-high by 5-foot-wide slots per row (photograph A5) in the upstream skin plate of the bulkhead proved to be the most effective of the three schemes tested. The 6-inch-high slots entrained no air and passed a discharge of 23,400 cfs with acceptable turbulence. Full-height vertical deflectors projecting 12 inches into the flow were installed at the PC of the downstream nose curve of the inner piers (plate A4) to minimize upwelling in the skeleton bay resulting from flow concentration in the left downstream corner of the skeleton unit.

A6. Although the bulkhead with 6-inch-high slots in the upstream skin plate met the previously established design criteria, concerns were raised as to the potential for fish to be swept through the slots and impinge on the flanges of the bulkhead crossmembers (I-beams) downstream of the skin plate. With the bulkhead reversed (skin plate on downstream side of I-beams), excessive upwelling occurred primarily as a result of flow impingement in the operating gate slots. To better observe the flow conditions causing the upwelling in the operating gate slots, the simplified model of one bay of the intake was constructed (paragraph A2). Observations made of one of the bulkheads with 6-inch orifices in an upstream skin plate and with exposed beams downstream indicated that the jets from the top center slots impinged on the beam flanges and dispersed rapidly in the vertical direction. The return flow along the roof

downstream from the bulkhead deflected the center jets upward causing impingement on the downstream edge of the gate well. On the sides, the return eddy overrode the top side jets and impinged on the upstream edge of the gate well. The deflected side jets expanded into the gate slots causing upwelling in the slots within the gate well. Air was entrained in the well due to the turbulent water surface. When horizontal plates were installed within the bulkhead from the skin plate to the edges of the flanges downstream (forming box beams and tubes of constant cross section), the jets from the top slots were deflected upward by the return flow and impinged on the downstream edge of the gate well along its entire length. The strong rolling flow in the well continuously entrained air. Pressure in the top tube just downstream from the skin plate was -16 feet of water.

A7. In an effort to provide increased fish protection and better flow conditions, bulkheads with converging tubes were investigated. The initial design contained 15 rows of 3 tubes, each with 6-inch by 5-foot orifices spaced 2.67 feet on centers and with tops and bottoms on slopes of 1V on 4.78H. The tubes were located in the lower 40 feet of the bulkheads as indicated by the earlier tests. The bulkheads proved to be too efficient (discharge 26,480 cfs) and created well-defined high-velocity jets resulting in excessive turbulence in the skeleton bay and air entrainment at the operating gate slots in all three bays of the intake. With the top three rows of orifices covered in each bulkhead, the discharge was reduced to 20,690 cfs, and although air was not entrained, turbulence within the skeleton bay increased. When the right draft tube was completely blocked and only the top row of orifices was covered, a very calm water surface existed in the skeleton bay without air entrainment; however, the average hydraulic head on the downstream wall of the bay was 17.1 feet--exceeding the criteria of 10 feet.

A8. The orifice-tube concept was also tested with the bulkheads reversed; i.e., the tubes diverged in the direction of flow with upstream orifice control. With all orifice tubes and both draft tubes open, the water surface in the skeleton bay was very calm and exhibited no tendencies of air entrainment; however, the discharge was only 19,550 cfs. The discharge was increased to 27,140 cfs by adding two rows of orifice tubes and decreasing the divergence to 1V on 8.05H (photographs A6 and A7). However, the water surface in the skeleton bay became very turbulent and the high-velocity flow under the operating gate drew the water surface in the gate slot down which subsequently drew in and entrained air. Additionally, pressures as low as -47 feet were measured (in the model) just inside the tube throats. Covering the top two rows of diverging tubes did not eliminate the air entrainment at the operating gate well.

Recommended Plan

A9. Due to the problems encountered with the diverging tube concept, further improvements were attempted with the converging tubes. To reduce the discharge, turbulence, and air entrainment which occurred with the initial convergent-tube design (paragraph A7), the height of the orifices in the top seven rows of tubes was reduced to 4 inches. With this modification, the discharge was reduced to an acceptable 21,500 cfs. Flow conditions in the skeleton were considered acceptable (photographs A8 and A9), and although turbulence in the bay was still quite noticeable, the water surface in the operating gate slot was calm and air was not entrained. The 12-inch deflectors on the face of the inner piers which were developed during initial model tests (paragraph A5) did not entirely eliminate upwelling in the left downstream corner of the bay. Although the 4-inch openings were narrower than the 5½-inch openings of the

intake trashracks, the trash problem was reconsidered and determined to be minor because the bulkheads would be below the level of major concentration of trash in the reservoir.

Little Goose Slotted Bulkhead

A10. As the 1971 spring runoff and construction deadlines drew nearer, development of the tube-type bulkheads was continued in an attempt to have a workable design for testing at the Little Goose project during the freshet. The contract bulkhead (photographs A10 and A11 and plate A-5) was based on the previously developed Lower Granite converging tube design. The slots in the top seven rows were 4 inches high, and the remaining eight rows were 6 inches high with the slot tubes converging on slopes of 1 on 4.27 and 1 on 4.78, respectively. Lower Granite water surface elevations were used in the evaluation of the bulkhead; corresponding Little Goose elevations may be obtained by subtracting 98 feet. The skeleton unit discharged 21,200 cfs (discharge coefficient 0.932) with 99 feet of head between forebay and tailwater. The discharge rating data for the contract bulkhead is listed in table A1 and shown on plate A6. Subsequent tests revealed that by changing the bottom two rows from 4- to 6-inch-high orifices an increase in discharge of 1,000 cfs per skeleton unit could be obtained without sacrificing acceptable flow conditions. This change, however, was not incorporated into the Little Goose contract bulkhead plan. Positive pressures were observed within the throats of the converging tubes and on the piers at the operating gate slots. Observed pressures and piezometer locations are shown in table A2. The maximum head differential between the water surface in the skeleton bay and the tailrace was 7.6 feet, which was less than the maximum allowable head differential of 10 feet. A minimum velocity barrier of approximately 19 and 16 fps existed along the centerline and sidewalls, respectively (plates A7 and A8), and exceeded the minimum fish-blocking velocity of 15 fps.

A11. The Little Goose contract bulkhead tests were accomplished with the full-height 12-inch deflector previously developed (paragraph A5 and plate A4) installed on the face of inner piers to reduce flow concentration in the downstream left corner of the skeleton bay. Flow directions within the skeleton bay are shown on plate A9. Roller action in the skeleton bay created a turbulent water surface (photograph A12) and continued into the intake exit as shown by the velocity profiles on plate A10. Water surface elevations and flow patterns in the skeleton bay were the same both with and without the No. 1 stoplog in the draft tube exit. In the model, small vortices which formed in the upstream corners of the skeleton bay entrained air that resurfaced in the bay. Subsequent observation in the prototype with the contract bulkheads and 12-inch deflectors installed indicated that surface turbulence prevented any substantial vortex formation. Tailrace velocities measured in the model both with and without the No. 1 stoplog in the draft tube exit are shown on plates A11 and A12, respectively. Surface turbulence in the tailrace area (photographs A13 and A14) was acceptable.

Miscellaneous Tests, Little Goose Bulkhead

A12. Prior to actual operation of the prototype contract bulkhead, tests were made to determine the effectiveness of the design with varying tailwater and forebay elevations. With normal and minimum forebay elevations 737 and 731, air was not entrained from the gate slot until the tailwater was lowered to elevations 631.0 and 630.8, respectively (approximately 5 feet below minimum tailwater at Little Goose Dam). Small quantities of air were entrained in the skeleton bay by surface turbulence with all tailwater levels below about elevation 644, but as discussed in paragraph A11 the air resurfaced in the bay and was not carried into the draft tube.

A13. In the model, flow conditions during introduction of water to the skeleton bay with the contract bulkheads in place were satisfactory. With all of the varied combinations of gate operation, the water surface in the skeleton bay was quite turbulent and air was entrained. The water surface differential across the downstream wall of the bay stabilized at approximately 6 feet with all three gates open; however, a maximum differential of 8 feet existed for short periods of time during the gate opening operation.

A14. As previous tests (paragraph A8) indicated that diverging tubes were effective but limited the discharge capability, tests of the Little Goose bulkhead with diverging tubes were conducted. To increase discharge, diverging-tube bulkheads were built with 15 rows of 6 3/8-inch-high orifices but without the center vertical beam of the Little Goose design (photographs A15 and A16). With Lower Granite test conditions--forebay and tailwater elevation 737 and 638 respectively--the unit discharge was 21,600 cfs. The water surface in the skeleton bay was quite turbulent, and the condition was not improved over that with the Little Goose contract bulkheads. Minimum pressures in the throat of the tubes just downsteam from the orifices were -14 feet. Two of the bulkheads having 6-3/8-inch-high diverging-tube-type orifices were modified to have 4-inch-high converging-tube-type orifices in the two top rows and were tested in both the full skeleton unit and the single intake bay models. With the change, the skeleton bay was quite turbulent with little improvement indicated. When the inflow discharge was momentarily disrupted, the water surface in the operating gate well drew down and air was entrained at the slots by a tight return flow roller which remained stable once it formed. The problem had not been observed with the Little Goose contract bulkheads which were then reinstalled and observed. With these bulkheads, roller action did occur and air was entrained when the bottom of the operating gate well was

just submerged. Due to the instability, turbulence, and air problems, development of a diverging-tube design was discontinued.

Summary

A15. Two 1:40-scale models were used to develop the design of slotted bulkheads for installation in the generator skeleton bays to reduce air entrainment and subsequent nitrogen concentration which may be harmful to migrating fish.

A16. Through the model study, a converging-tube, slotted bulkhead design was developed which met design criteria and minimized the nitrogen supersaturation problem. The design was field tested at the Little Goose Dam project where measurements showed that there was no increase in nitrogen supersaturation in flows from the skeleton units with the bulkheads in place.

Model Study

Lower Granite Skeleton Unit

TABLE A1

DISCHARGE

Little Goose Contract Bulkhead

Discharge per Unit in CFS	Head-Forebay to Tailwater in Feet
18,120	74.40
18,800	80.14
19,200	83.01
19,320	83.76
19,750	86.74
20,010	89.34
20,020	89.58
20,050	89.89
20,710	95.02
21,160	99.10
21,180	99.84
21,250	100.10

NOTE: Details of skeleton unit and bulkhead shown on plates A1, A2, and A5.

Model Study

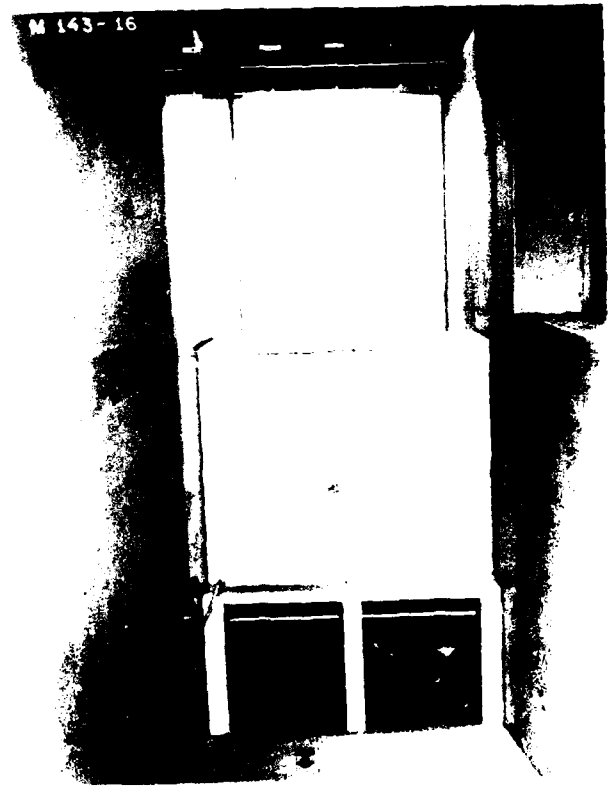
Lower Granite Skeleton Unit

TABLE A2

PRESSURES

NOTE: Details of skeleton unit and bulkhead shown on plates A1, A2, and A5

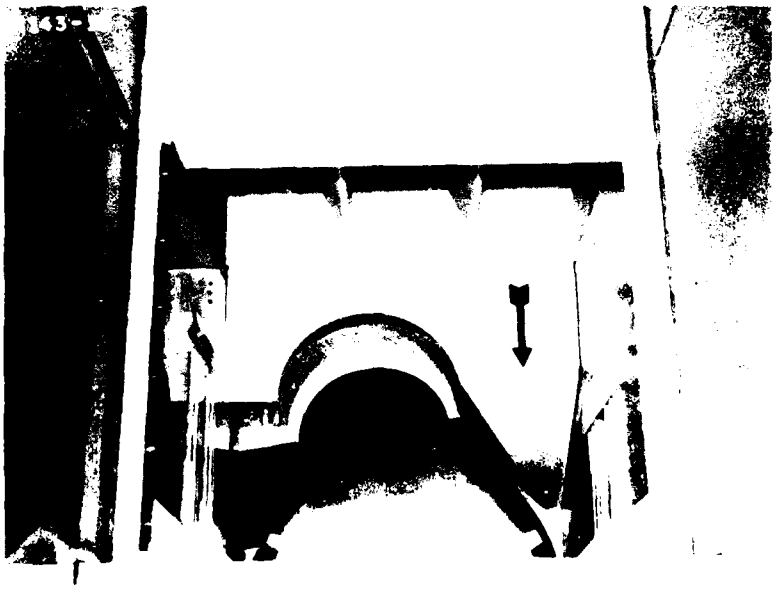
Photograph A1.
Intake
Operating gates closed



Photograph A2.
Draft tube exits

Skeleton unit

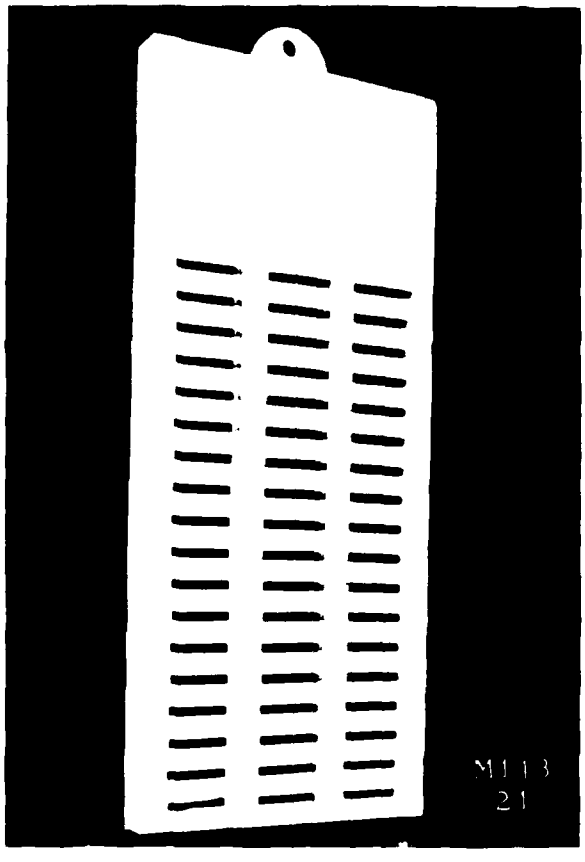
Photograph A3.



Photograph A4.

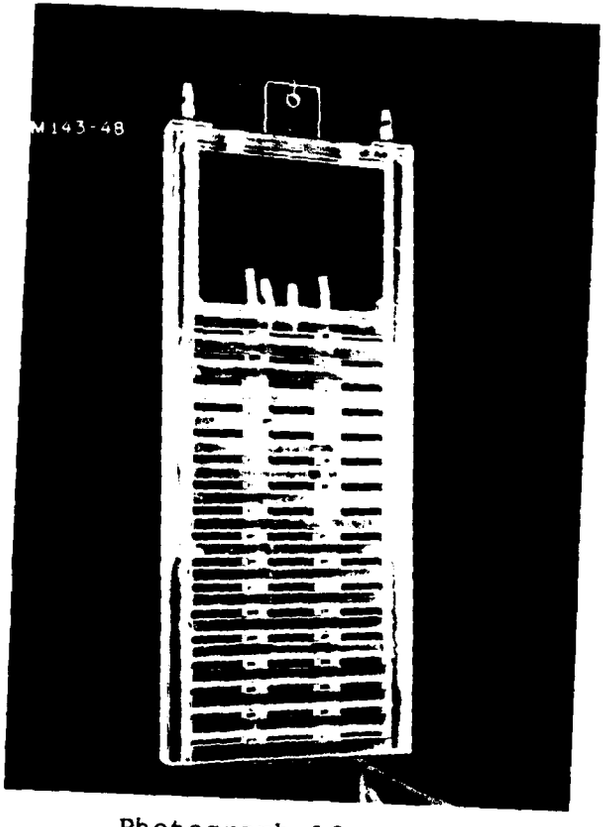
Skeleton bay

Overhead view

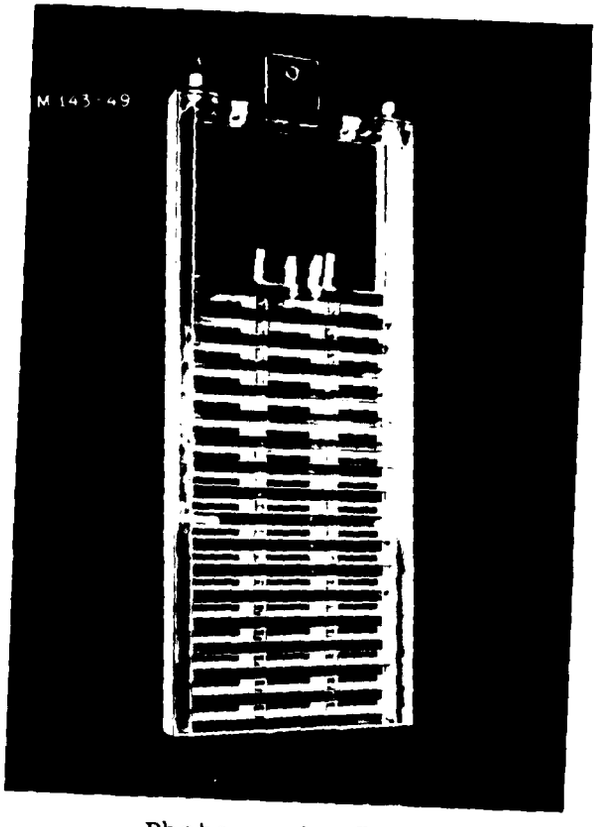


6-inch by 5-foot slots

Photograph A5. Bulkheads with eighteen horizontal rows of slotted orifices in an upstream skin plate.



Photograph A6.
Upstream view



Photograph A7.
Downstream view

Bulkhead with seventeen rows of 6-inch by 5-foot diverging tube orifices with 1 on 8.05 divergence

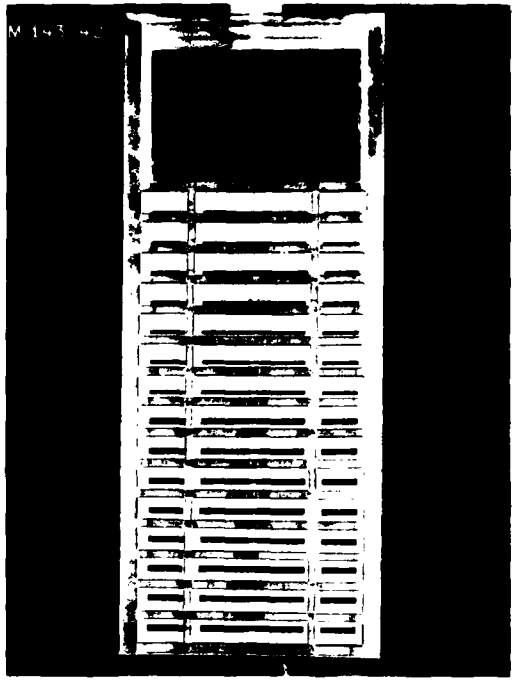
Photograph A8.
Skeleton bay and powerhouse tailrace from downstream

Photograph A9.
Skeleton bay

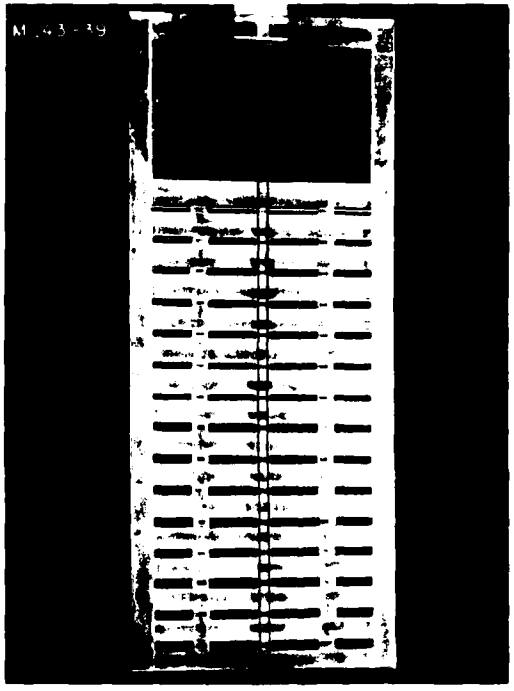
Converging tube design with 15 rows per bulkhead
Orifice heights: top 7 rows 4 inches, bottom 8 rows 6 inches

Discharge 21,500 cfs, forebay elevation 737.0, tailwater elevation 638.0, no stoplogs in draft tube exits

Full height, 12-inch deflectors on intake piers



Photograph A10.
Upstream view



Photograph A11.
Downstream view

Little Goose contract bulkhead

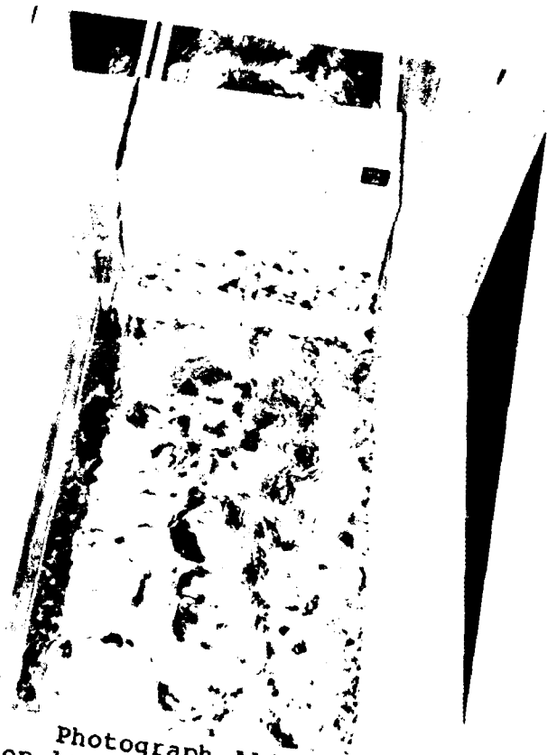
Fifteen rows of converging tube orifices, top 7 rows 4 inches high, remaining rows 6 inches high

Photograph A12.

Flow conditions with Little Goose contract bulkheads
and 12-inch deflectors
No stop logs in draft tube exits

Forebay elevation 737.0, tailwater elevation 638.0

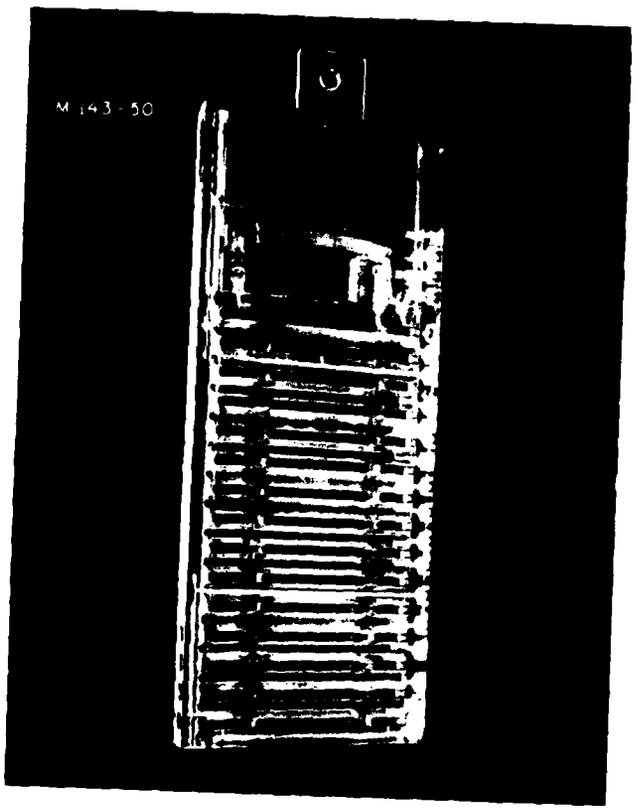
Photograph A13.
No stop log in draft tube exits



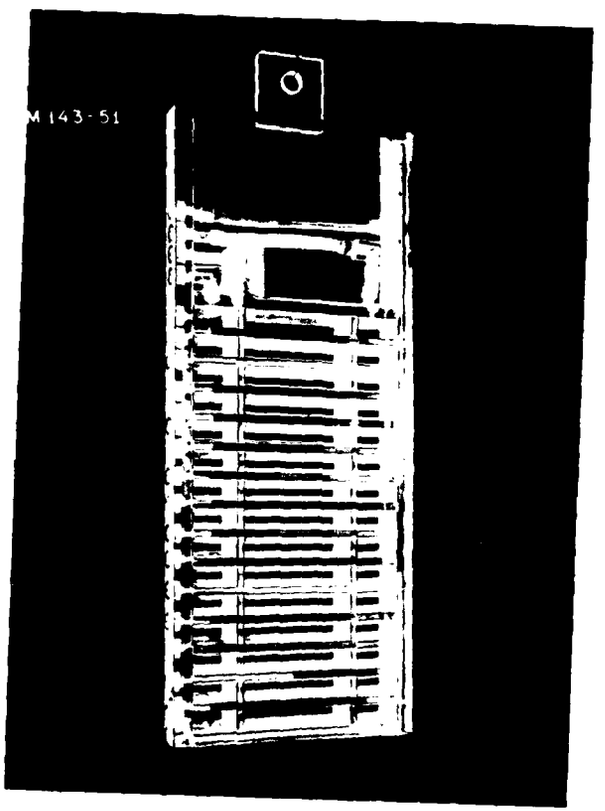
Photograph A14.
No. 1 stop logs in draft tube exits

Flow conditions with Little Goose contract bulkheads and 12-inch deflectors

Forebay elevation 737.0, tailwater elevation 638.0



Photograph A15.
Upstream view



Photograph A16.
Downstream view

Bulkhead with 15 rows of diverging tube orifices 6 3/8-inch high

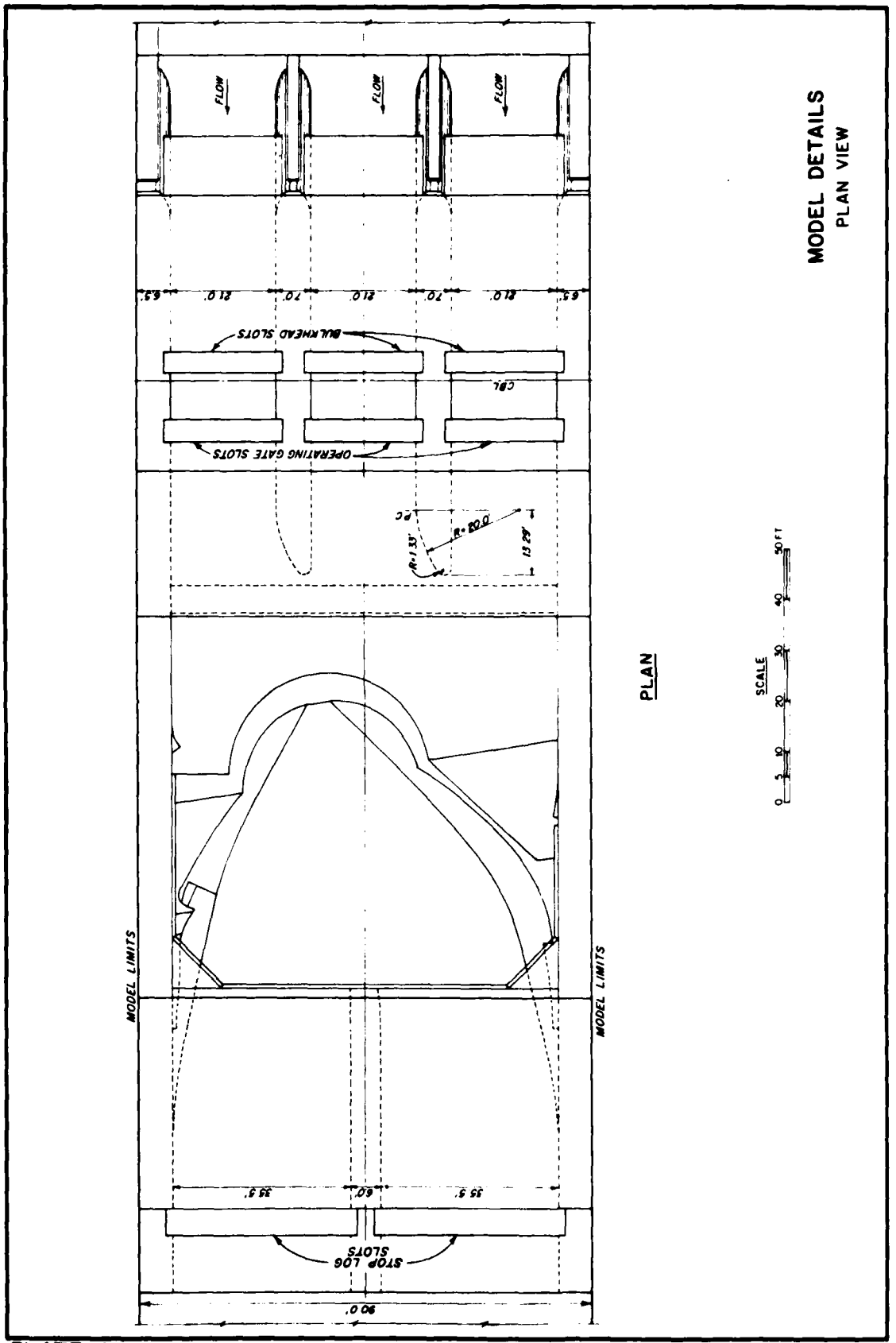
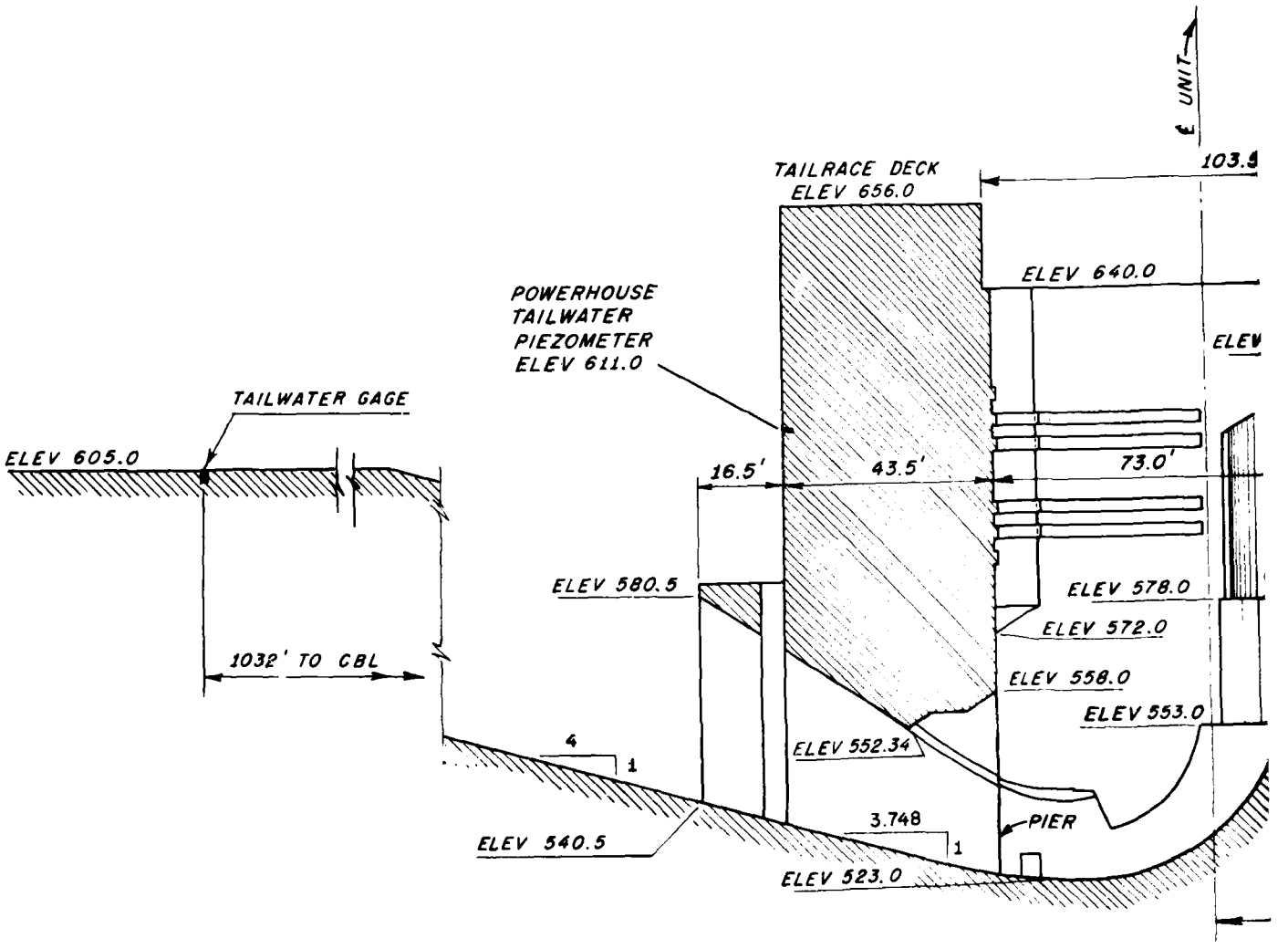
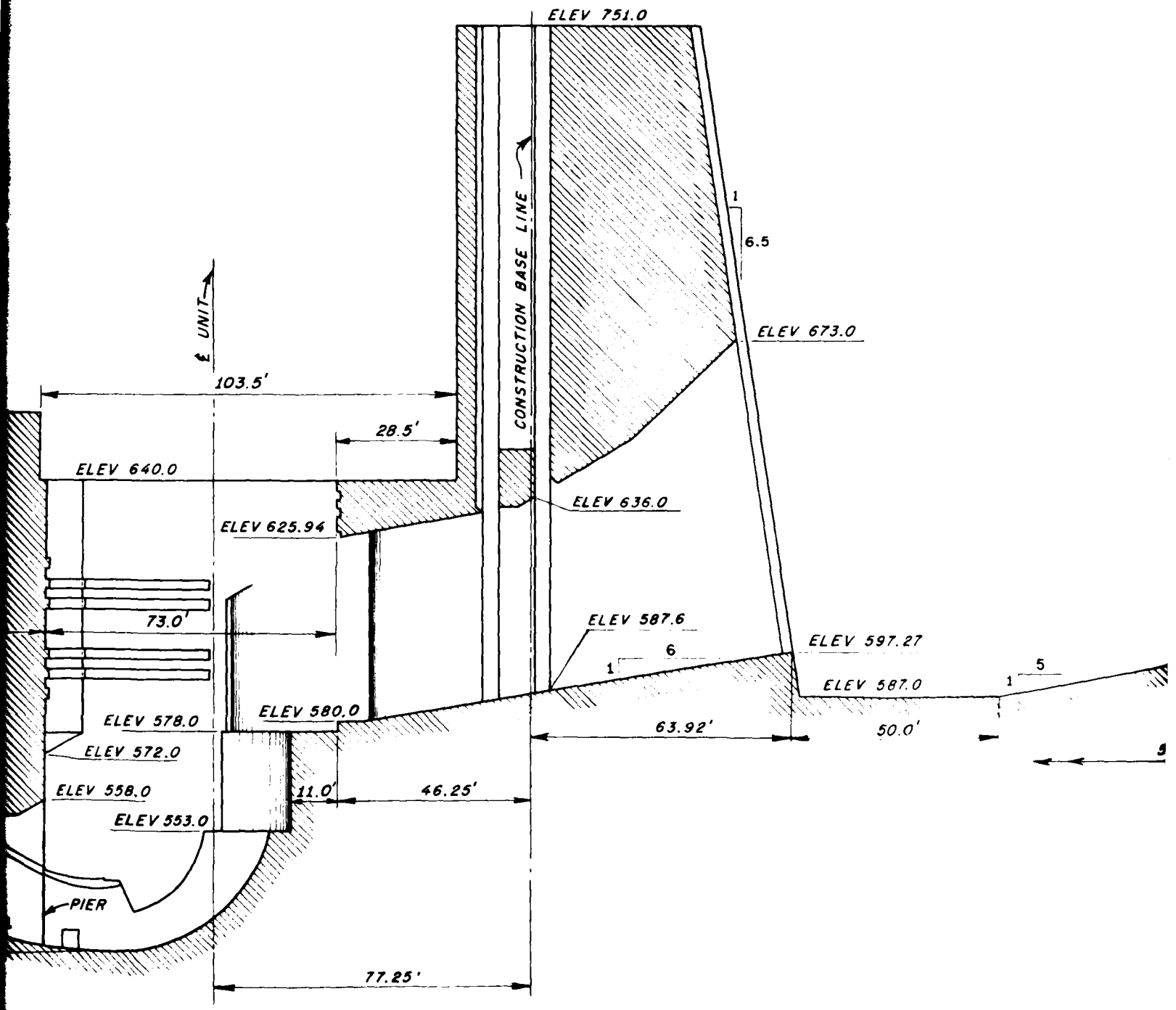

MODEL DETAILS
PLAN VIEW
FLOW
FLOW
FLOW
63'
210'
70'
210'
70'
210'
63'
BULKHEAD SLOTS
CBL
OPERATING GATE SLOTS
R=20.0
R=1.33'
13.29'
PLAN
SCALE
0
5
10
20
30
40
50 FT
MODEL LIMITS
MODEL LIMITS
33.5'
60'
33.5'
STOP LOG SLOTS
900'

PLATE A1



SECTIO

0 0.5 1
0 25

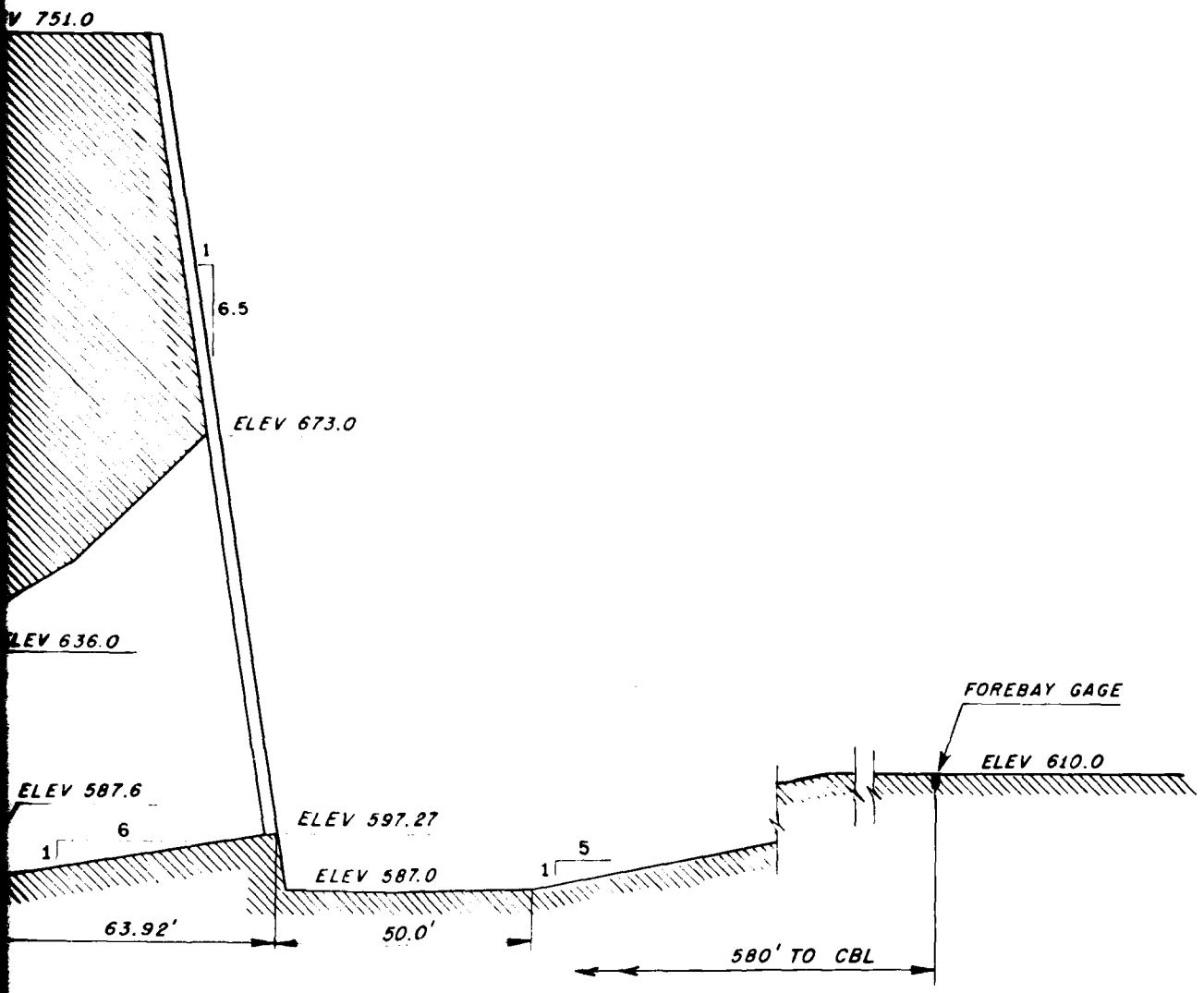


SECTION THROUGH UNIT

SCALES

0 0.5 1 1.5 2 2.5 FT MODEL

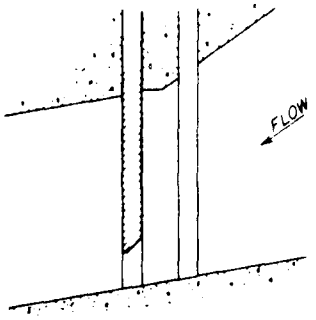
0 25 50 75 100 FT PROTOTYPE



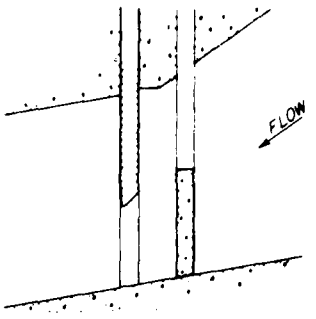
MODEL DETAILS
SECTIONAL VIEW

PE

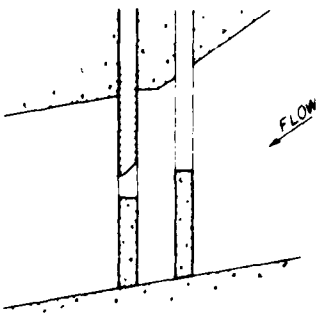
PLATE A2



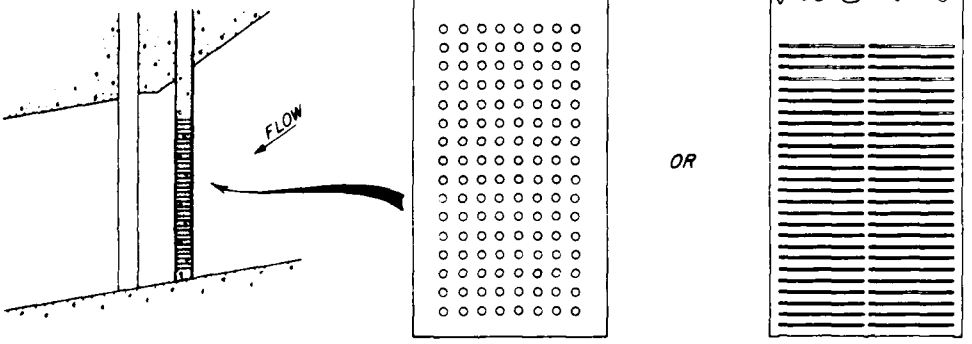
OPERATING GATES



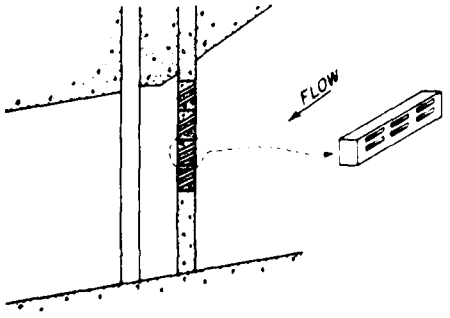
OPERATING GATES AND STOP LOGS IN BULKHEAD SLOTS



OPERATING GATES AND STOP LOGS IN BULKHEAD AND GATE SLOTS



BULKHEADS WITH ORIFICES

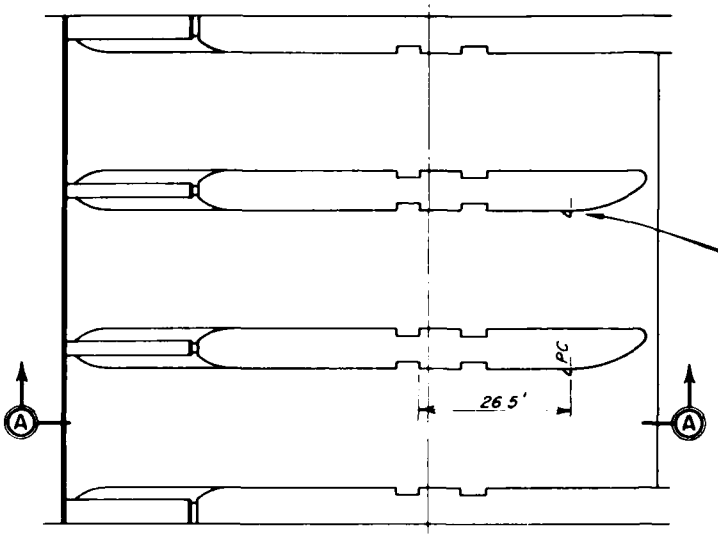


STOP LOGS WITH SLOPING ORIFICES IN BULKHEAD SLOTS

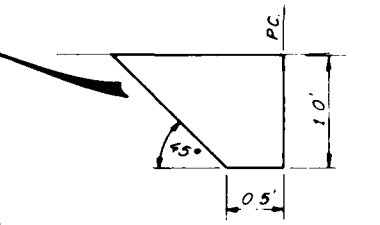
NOTE
DETAILS OF SKELETON BAY SHOWN ON PLATE A1 AND A2.

FLOW CONTROL PLANS

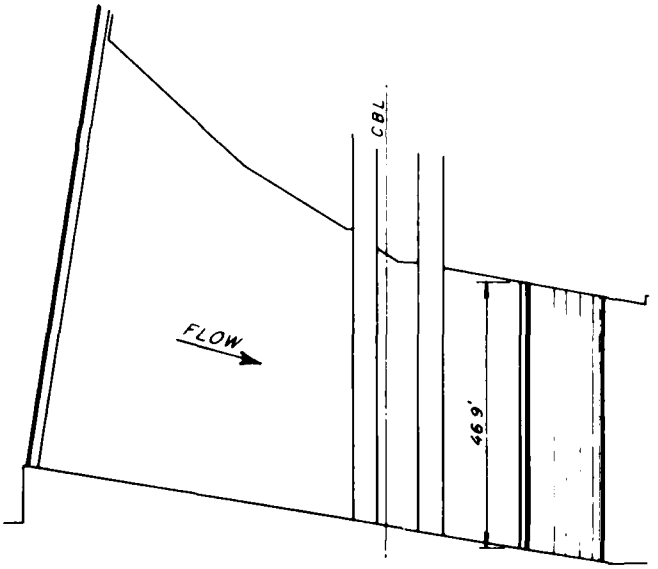
PLATE A3



PLAN THROUGH INTAKE



DEFLECTOR DETAIL



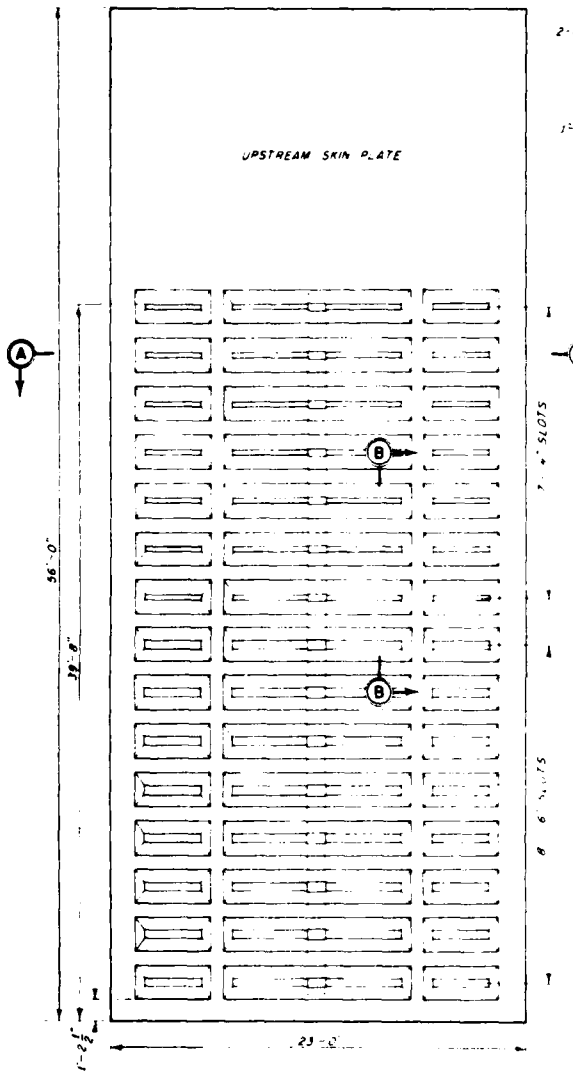
SECTION A-A

NOTE

INTAKE DETAILS SHOWN ON PLATES A1 AND A2

12-IN. DEFLECTORS

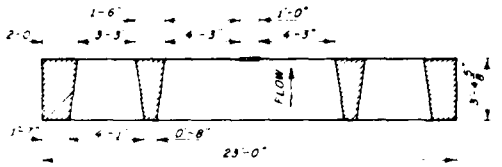
PLATE A4



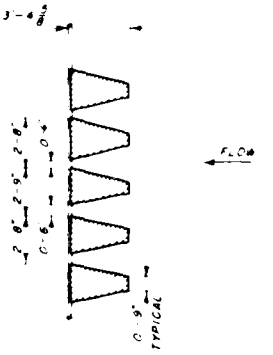
UPSTREAM ELEVATION

SCALE

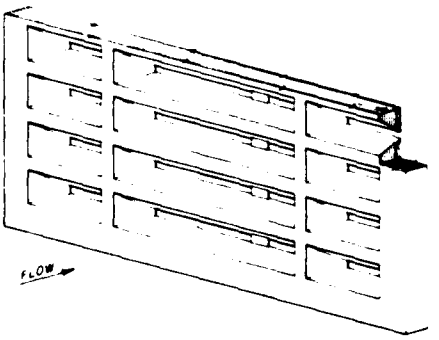
0' 5 10 15 20 25'



SECTION A-A



SECTION B-B

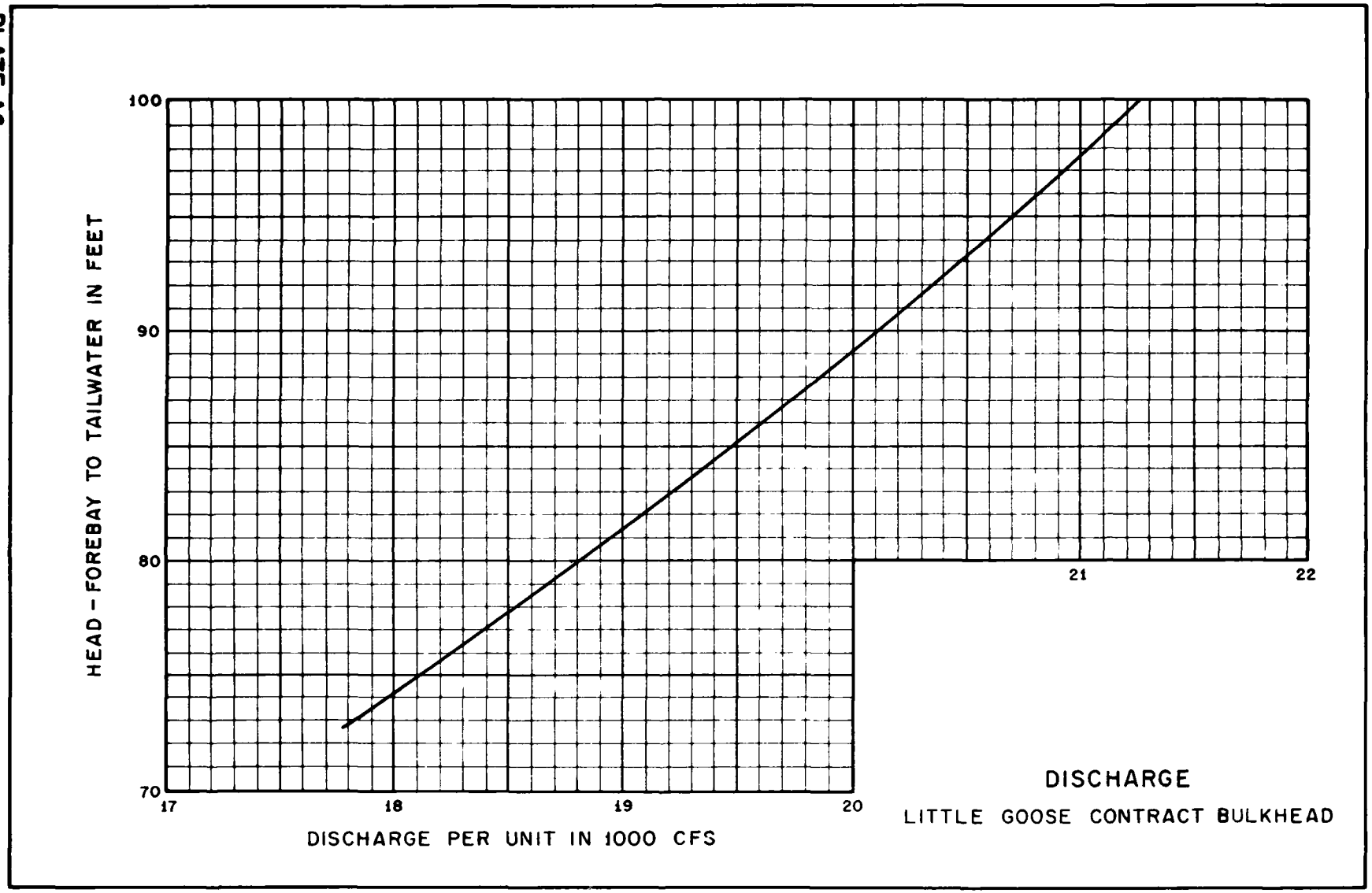


ISOMETRIC VIEW

LITTLE GOOSE CONTRACT BULKHEAD

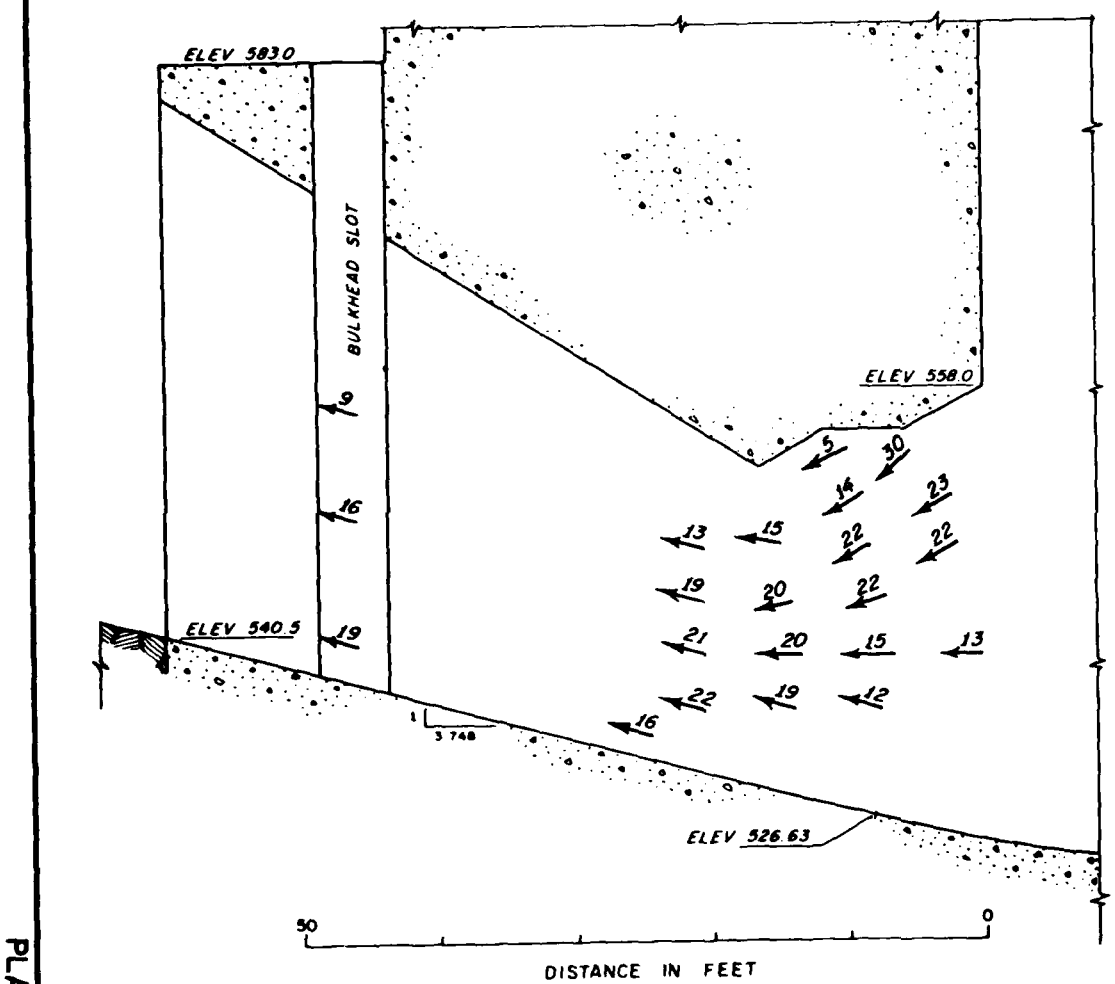
PLATE A5

PLATE A6



DISCHARGE

LITTLE GOOSE CONTRACT BULKHEAD



OPERATING CONDITIONS

HEAD, FOREBAY TO TAILWATER, 99 FT
TOTAL UNIT DISCHARGE 21200 CFS

LEGEND

13 VELOCITY IN FPS

NOTE

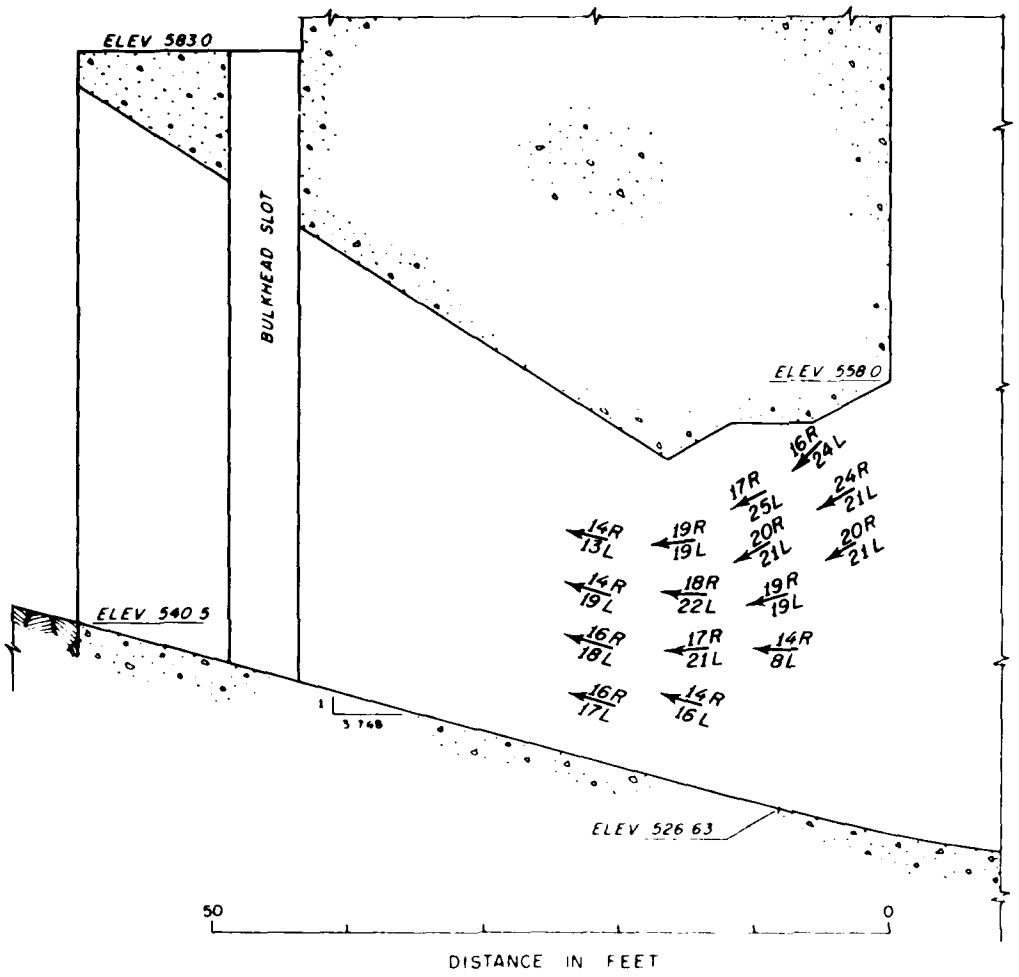
DETAILS OF SKELETON UNIT AND BULKHEADS SHOWN ON PLATES A1, A2, AND A5

VELOCITIES
CENTER LINE OF LEFT DRAFT TUBE

LITTLE GOOSE CONTRACT BULKHEAD
AND 12-IN. DEFLECTORS

PLATE A7

PLATE A8



OPERATING CONDITIONS

HEAD, FOREBAY TO TAILWATER, 99 FT
TOTAL UNIT DISCHARGE 21200 CFS

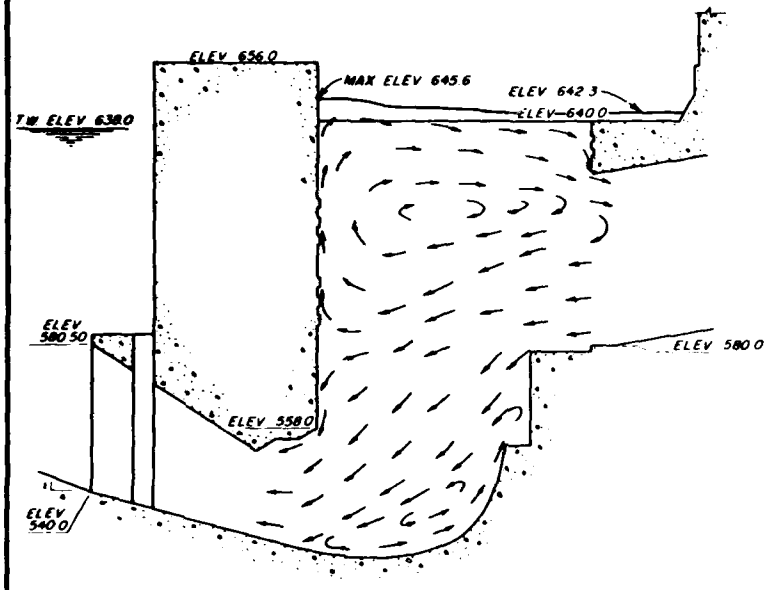
LEGEND

19 VELOCITY IN FPS
R 4 FT FROM RIGHT WALL
L 4 FT FROM LEFT WALL

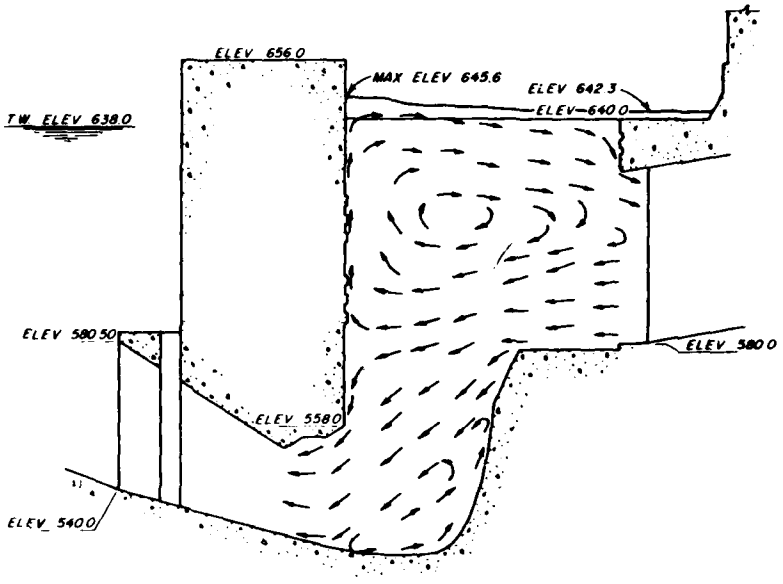
NOTE

DETAILS OF SKELETON UNIT AND BULKHEADS SHOWN ON PLATES A1, A2, AND A5.

VELOCITIES
SIDES OF LEFT DRAFT TUBE
LITTLE GOOSE CONTRACT BULKHEAD AND 12-IN DEFLECTORS



CENTER LINE OF RIGHT DRAFT TUBE



CENTER LINE OF LEFT DRAFT TUBE

PLATE A9

OPERATING CONDITIONS

HEAD, FOREBAY TO TAILWATER 99 FT
TOTAL UNIT DISCHARGE 21 200 CFS

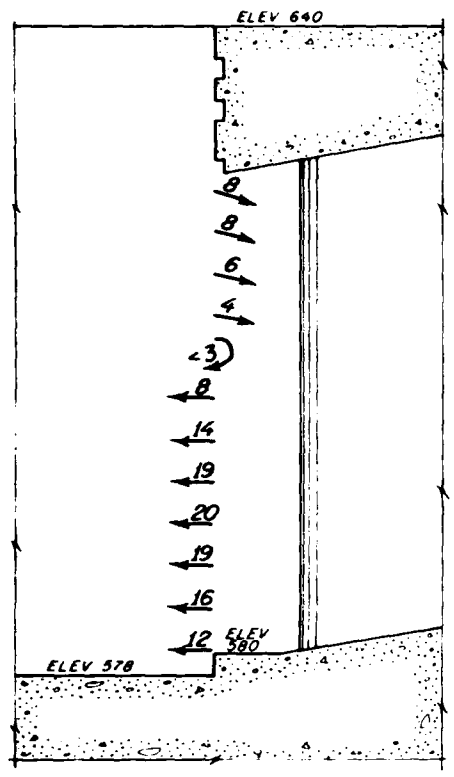
NOTE

DETAILS OF SKELETON UNIT AND BULKHEADS SHOWN ON PLATES A1, A2, AND A5

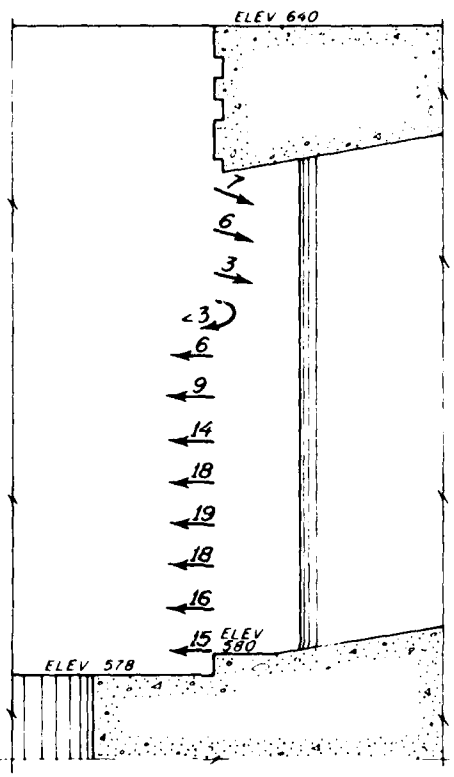
FLOW DIRECTIONS
SKELETON BAY

LITTLE GOOSE CONTRACT BULKHEAD AND 12-IN. DEFLECTORS

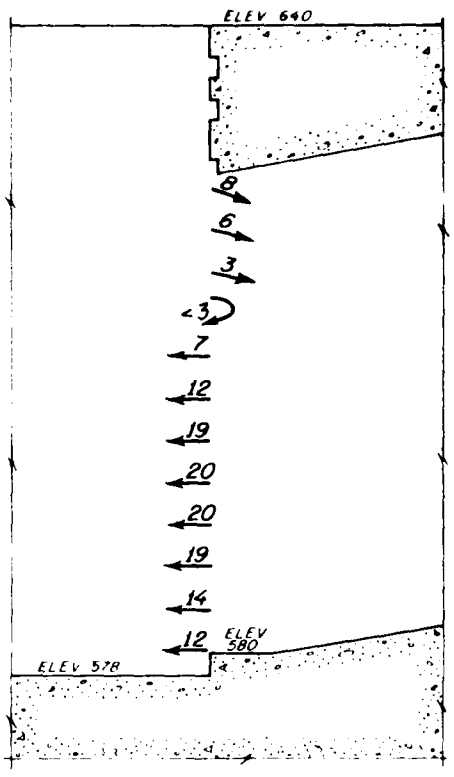
PLATE A10



LEFT



CENTER



RIGHT

OPERATING CONDITIONS

FOREBAY ELEVATION 737
HEAD, FOREBAY TO TAILWATER, 99 FT
TOTAL UNIT DISCHARGE 21 200 CFS

LEGEND

12 VELOCITIES IN FPS

NOTE

DETAILS OF SKELETON UNIT AND BULKHEADS SHOWN ON PLATES A1, A2, AND A5

VELOCITIES
CENTER LINE OF INTAKE EXITS
LITTLE GOOSE CONTRACT BULKHEAD AND 12-IN DEFLECTORS

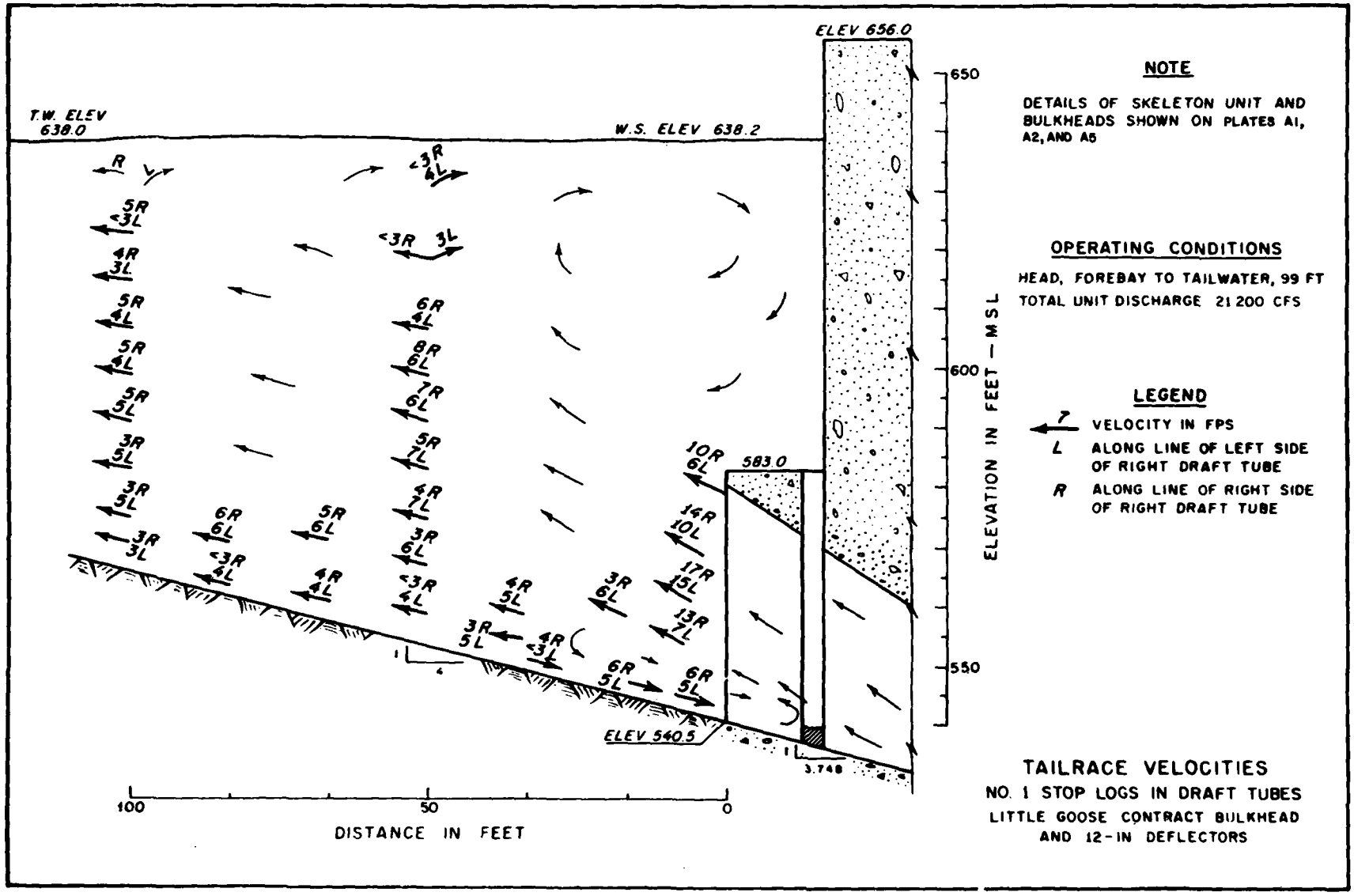
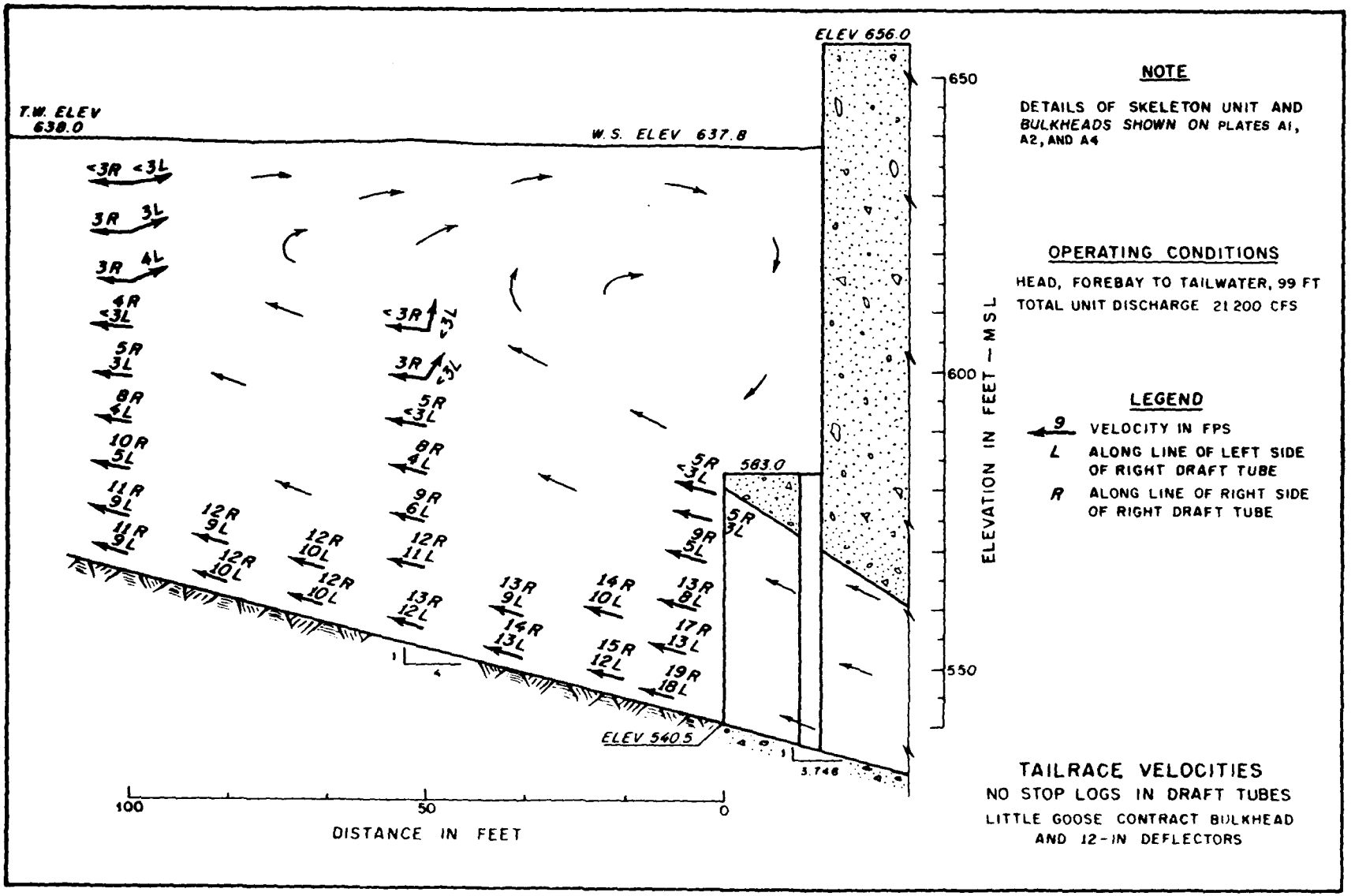
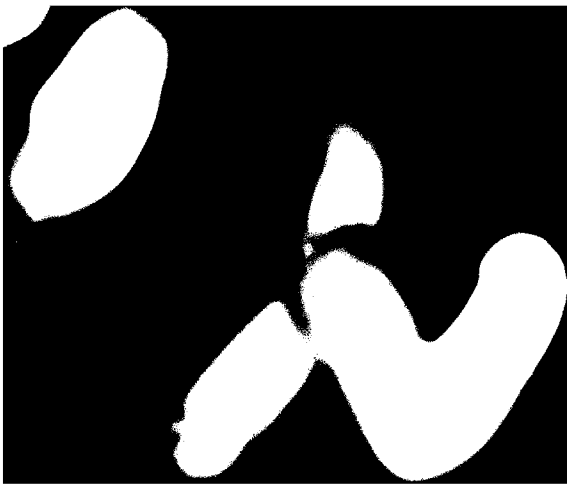

ELEV 656.0
T.W. ELEV 638.0
W.S. ELEV 638.2
650
600
550
ELEVATION IN FEET — MSL
583.0
ELEV 540.5
3.748
100
50
0
DISTANCE IN FEET
NOTE
DETAILS OF SKELETON UNIT AND BULKHEADS SHOWN ON PLATES A1, A2, AND A5
OPERATING CONDITIONS
HEAD, FOREBAY TO TAILWATER, 99 FT
TOTAL UNIT DISCHARGE 21 200 CFS
LEGEND
7 VELOCITY IN FPS
L ALONG LINE OF LEFT SIDE OF RIGHT DRAFT TUBE
R ALONG LINE OF RIGHT SIDE OF RIGHT DRAFT TUBE
TAILRACE VELOCITIES
NO. 1 STOP LOGS IN DRAFT TUBES
LITTLE GOOSE CONTRACT BULKHEAD AND 12-IN DEFLECTORS

PLATE A11

PLATE A12

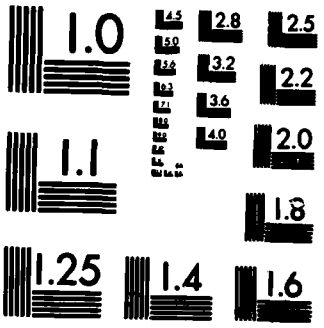

ELEV 656.0
T.W. ELEV 638.0
W.S. ELEV 637.8
650
600
550
ELEVATION IN FEET — MSL
583.0
ELEV 540.5
3.748
100
50
0
DISTANCE IN FEET
NOTE
DETAILS OF SKELETON UNIT AND BULKHEADS SHOWN ON PLATES A1, A2, AND A4
OPERATING CONDITIONS
HEAD, FOREBAY TO TAILWATER, 99 FT
TOTAL UNIT DISCHARGE 21 200 CFS
LEGEND
9 VELOCITY IN FPS
L ALONG LINE OF LEFT SIDE OF RIGHT DRAFT TUBE
R ALONG LINE OF RIGHT SIDE OF RIGHT DRAFT TUBE
TAILRACE VELOCITIES
NO STOP LOGS IN DRAFT TUBES
LITTLE GOOSE CONTRACT BULKHEAD AND 12-IN DEFLECTORS

DATE
FILME
DTIC



AD-A146 499 LOWER GRANITE DAM SNAKE RIVER WASHINGTON; HYDRAULIC MODEL INVESTIGATIONS(U) ARMY ENGINEER DIV NORTH PACIFIC BONNEVILLE OR DIV HYDRAULIC LAB R L JOHNSON ET AL. 3/3

UNCLASSIFIED AUG 84 TR-121-1 F/G 20/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SUPPLEMENTARY

INFORMATION

AD-A146499

Erratta

26 September 1984

SUBJECT: Revision to Technical Report No. 121-1, "Lower Granite Dam, Snake River, Washington," dated August 1984 - Hydraulic Model Investigation

Table A2 of the subject report is revised to incorporate the data not originally printed. The attached page should be substituted in the report.

Model Study

Lower Granite Skeleton Unit

TABLE A1

DISCHARGE

Little Goose Contract Bulkhead

Discharge per Unit in CFS	Head-Forebay to Tailwater in Feet
18,120	74.40
18,800	80.14
19,200	83.01
19,320	83.76
19,750	86.74
20,010	89.34
20,020	89.58
20,050	89.89
20,710	95.02
21,160	99.10
21,180	99.84
21,250	100.10

NOTE: Details of skeleton unit and bulkhead shown on plates A1, A2, and A5.

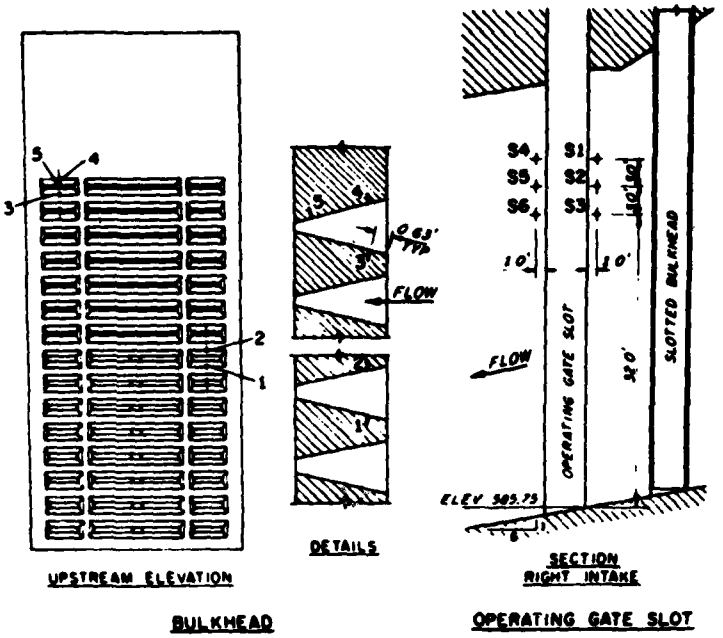
Model Study

Lower Granite Skeleton Unit

TABLE A2

PRESSURES

Little Goose Contract Bulkhead



BULKHEAD

OPERATING GATE SLOT

PIEZOMETER LOCATIONS

Piezometer Number	Pressure in Feet of Water
1	125
2	114
3	110
4	103
5	93
S1	17
S2	21
S3	24
S4	17
S5	21
S6	24

Operating Conditions: Discharge 21,200 cfs
Forebay Elev 737.0
Tailwater Elev 638.0

NOTE: Details of skeleton unit and bulkhead shown on plates A1, A2, and A5

TABLE A2 (Revised)

END

FILMED

4-85

DTIC